Light Duty Technology Cost Analysis, Power-Split and P2 HEV Case Studies

United States
Environmental Protection
Agency

Light Duty Technology Cost Analysis, Power-Split and P2 HEV Case Studies

Assessment and Standards Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

Prepared for EPA by
FEV, Inc.
EPA Contract No. EP-C-07-069
Work Assignment No. 3-3

NOTICE

This technical report does not necessarily represent final EPA decisions or positions. It is intended to present technical analysis of issues using data that are currently available. The purpose in the release of such reports is to facilitate the exchange of technical information and to inform the public of technical developments.

EPA United States Environmental Protection Agency

EPA-420-R-11-015
November 2011

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A. Executive Summary

The United States Environmental Protection Agency (EPA) contracted with FEV, Inc. to determine incremental direct manufacturing costs for a set of advanced light-duty vehicle technologies. The technologies selected are on the leading edge for reducing emissions of greenhouse gases in the future, primarily in the form of tailpipe carbon dioxide (CO_2).

In contrast to comparable cost analyses done in the past, which relied heavily on supplier price quotes for key components, this study is based to a large degree on teardowns of vehicles or vehicle systems that employ the new technologies and of similar vehicles or systems without the new technologies. Analysts with expertise in automotive design, materials, and manufacturing then compare the teardown components and evaluate the differences. Using databases for materials, labor, manufacturing overhead, and mark-up costs, the overall cost to manufacture individual parts and assemble them into systems are calculated and summed into final results. A model consisting of an extensive set of linked spreadsheets and associated macros has been developed to perform the calculations, to track the input data, identify sources of information, describe assumptions used in the case study, and provide analysis tools such as forecasting to future years.

To establish a consistent framework for all costing work, several primary technology and manufacturing assumptions were established that directly impact the cost parameters used in the analysis. For example, the manufacturing time period and location identifies the labor rate data uploaded into the analysis. The maturity level of the technology defines the mark-up rates (end-item scrap, corporate overhead/SG&A, profit, engineering, design and testing (ED&T)/research and development (R&D)) applied against the total manufacturing cost.

Examples of universal assumptions used for the cost analyses included in this report are as follows:

- Technology and manufacturing methods are considered mature in the 2009/2010 timeframe, e.g., well developed product designs, high production volumes, high first time manufacturing yields, significant marketplace competition, low field warranty.

- Manufacturing rates are considered high volume, i.e., approximately 450,000 units per year, and maintained throughout the product life.

- All OEM and supplier manufacturing locations are in North America (i.e., USA and Canada), unless otherwise stated.

- All manufacturing process and operations are based on standard/mainstream industrial practices.

- All material, labor and manufacturing overhead costs are based on 2009/2010 economics.

- All OEM mark-up will be applied using indirect cost (IC) multipliers. These are not within the scope of this analysis, but should be separately determined and applied to the results of this analysis to obtain the total (direct + indirect) manufacturing costs.

Since the manufacturing costs presented in this report are based on current automotive and/or surrogate industry manufacturing operations and processes, it is acknowledged that a reduction to the costs presented is very likely based on both product and manufacturing learning. Projected technology cost reductions, as a result of learning, are not covered as part of this analysis.

In addition, no attempt was made in the analyses to forecast the impact of material, labor, and/or manufacturing overhead rate changes. However, a sensitivity analysis has been added to predict the impact of changes in any of the costs.

The report begins by providing an overview of the costing methodology used to conduct the various analyses contained within this report. Additional details on the costing methodology can be found in EPA published report EPA-420-R-09-020 "Light-Duty Technology Cost Analysis Pilot Study" (http://www.epa.gov/OMS/climate/420r09020.pdf).

Following the costing methodology overview, the incremental cost impact of adding power-split hybrid electric vehicle (HEV) technology to a conventional baseline vehicle is discussed. The analysis is based on the detail teardown and costing of the hardware difference, applicable to the adaptation of power-split HEV technology found between the 2010 Ford Fusion HEV and an equivalent equipped 2010 Ford Fusion conventional powertrain vehicle. A description of the hardware required to create the power-split technology is highlighted and details on the costs are captured at various levels. **Figure A-1** is a simple illustration of the power-split technology analyzed highlighting key components within the power-split system boundary as well as those systems which impacted the net incremental direct manufacturing cost. Components within other vehicle systems (e.g., suspension, driveline, electrical feature) were also modified, however their differences were assessed to have no significant cost impact.

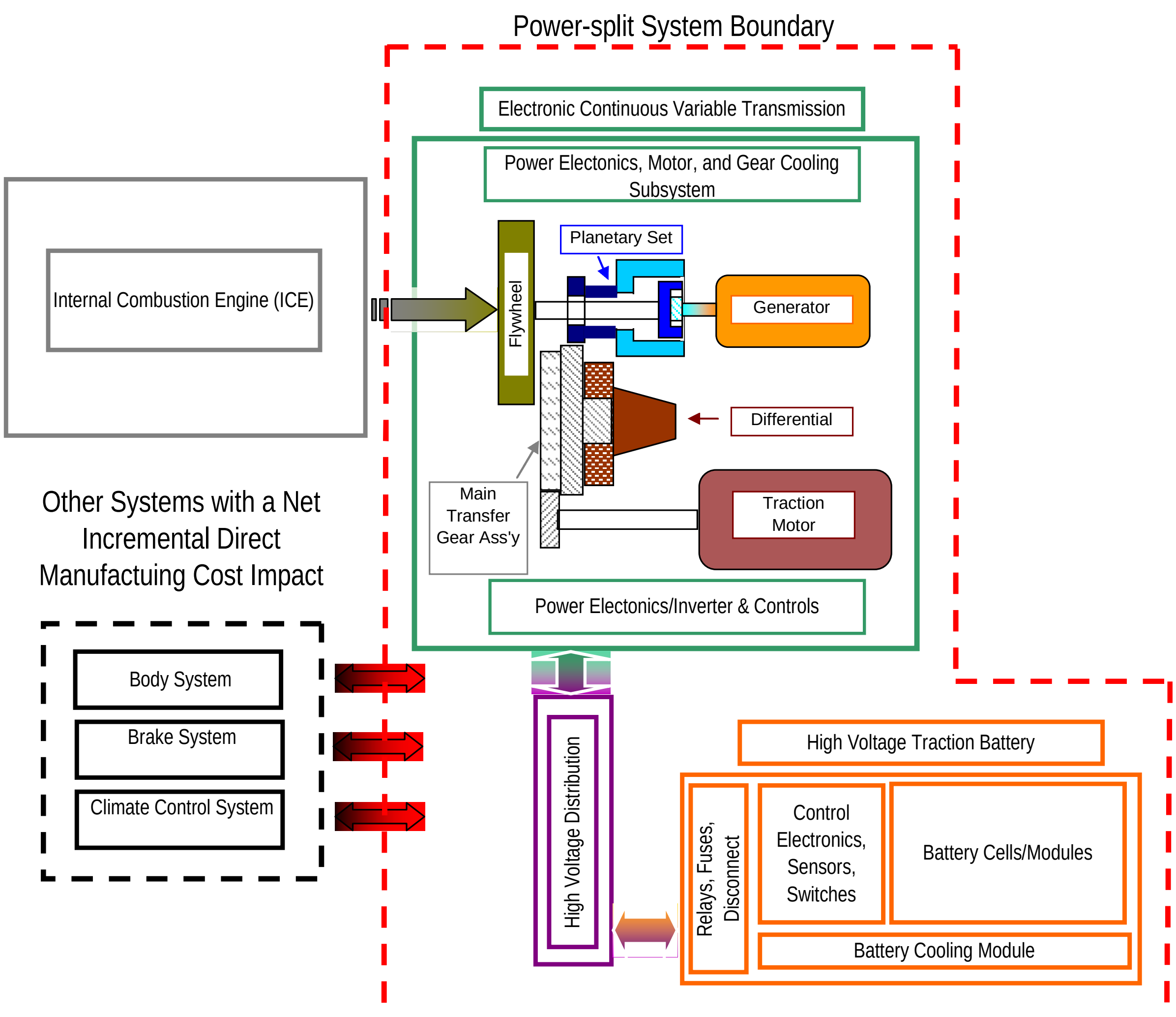


Figure A-1: Power-split System Diagram Illustrating Basic Concept

A summary of the incremental cost impact, broken down by major contributing vehicle system may be found in **Figure A-2**.

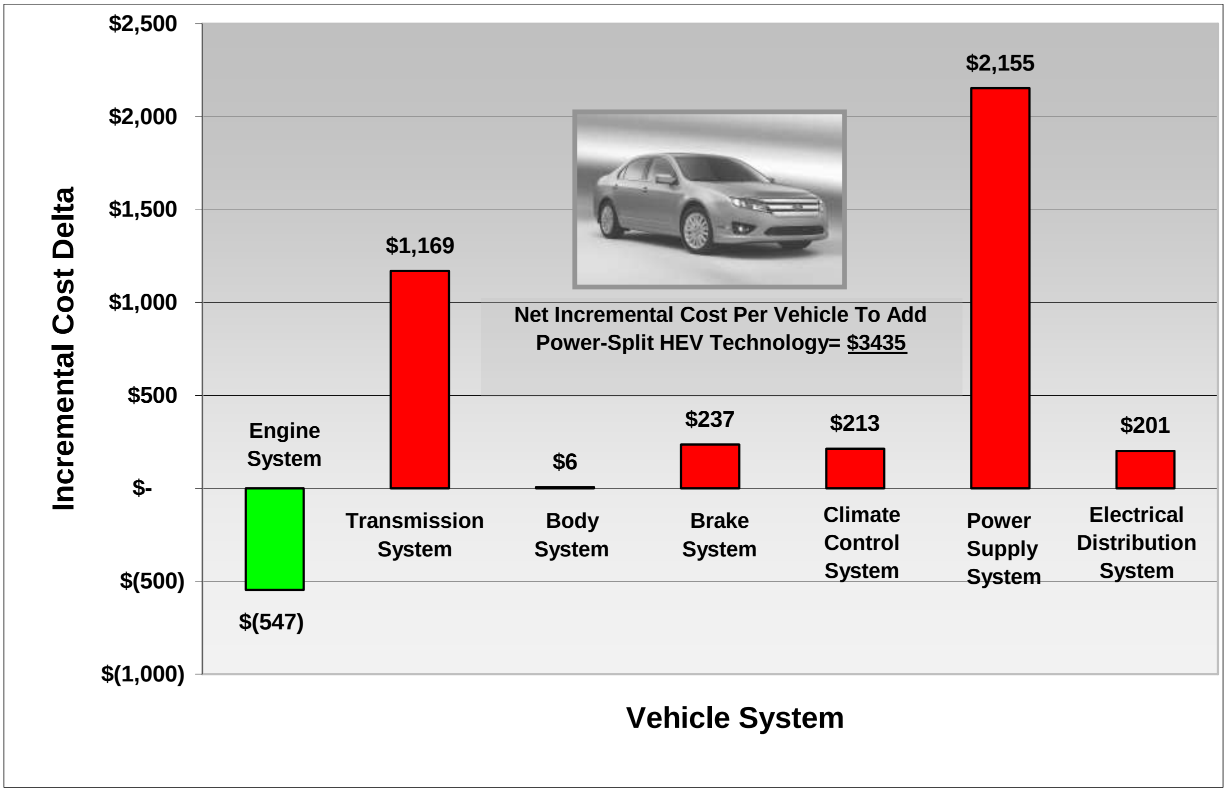


Figure A-2: Net Incremental Direct Manufacturing Cost to Add Power-Split HEV Technology to a Conventional Large Size Vehicle (i.e. 2010 Ford Fusion)

In addition, the incremental cost results for adding power-split HEV technology to other vehicle segments is presented. Using selected vehicle attributes (e.g., net vehicle horsepower, internal combustion engine horsepower, traction motor horsepower, traction motor battery size, wheel base, curb weight, interior volume) custom ratios were developed for scaling the Ford Fusion large size power-split HEV technology configuration, and associated incremental costs, to additional vehicle segments. **Table A-1** provides a summary of the incremental cost impact for adding the power-split technology to the sub-compact, small, and minivan vehicle segments. Note the power-split HEV technology was not considered applicable for the small and large truck classes.

Table A-1: Net Incremental, Direct Manufacturing Costs to Add Power-Split HEV Technology to a Range of Vehicle Segments

System ID	System Description	Calculated Incremental Manufacturing Cost			
		Subcompact Size Passenger Vehicle Segment (e.g. Ford Fiesta)	Compact-Small Size Passenger Vehicle Segment (e.g. Ford Focus)	Mid-Large Size Passenger Vehicle Segment (Ford Fusion)	Minivan-Large Size Passenger Vehicle Segment (e.g. Ford Flex)
010000	Engine System	$ (193.35)	$ (87.53)	**$ (547.00)**	$ (131.30)
020000	Transmission System	$ 1,008.12	$ 1,026.02	**$ 1,169.27**	$ 1,173.34
030000	Body System	$ 6.31	$ 6.31	**$ 6.31**	$ 6.31
060000	Brake System	$ 229.83	$ 232.20	**$ 236.68**	$ 241.96
120000	Climate Control System	$ 204.33	$ 207.89	**$ 213.46**	$ 230.48
140000	Electrical Power Supply System	$ 1,406.23	$ 1,594.08	**$ 2,154.80**	$ 2,463.98
180000	Electrical Distribution and Electronic Control System	$ 191.45	$ 196.19	**$ 201.50**	$ 203.75
000000	Net Incremental	$ 2,852.92	$ 3,175.16	**$ 3,435.01**	$ 4,167.81
Percent Decrease/Increase From Mid-Large Size Vehicle Segment		**- 17.0%**	**- 8.0%**	**N/A**	**+ 21.3%**

Lastly, utilizing both the Ford Fusion power-split HEV components and developed costs, and the Hyundai Avante lithium polymer battery module (sold domestically in South Korea) and its developed costs, an incremental cost was developed for a P2 HEV technology configuration, over a range of vehicle segments. The basic P2 configuration evaluated, shown in **Figure A-3**, consists of an integrated electric motor/generator and hydraulic clutch module positioned between a downsized internal combustion engine (ICE) and transmission. The electrical power supply/storage system consisted of high voltage lithium polymer battery pack; voltage and capacity matched to the electric motor/generator size and vehicle mass. The P2 HEV technology configuration considered in this analysis was not considered to have a significant all electric range (AER) capability.

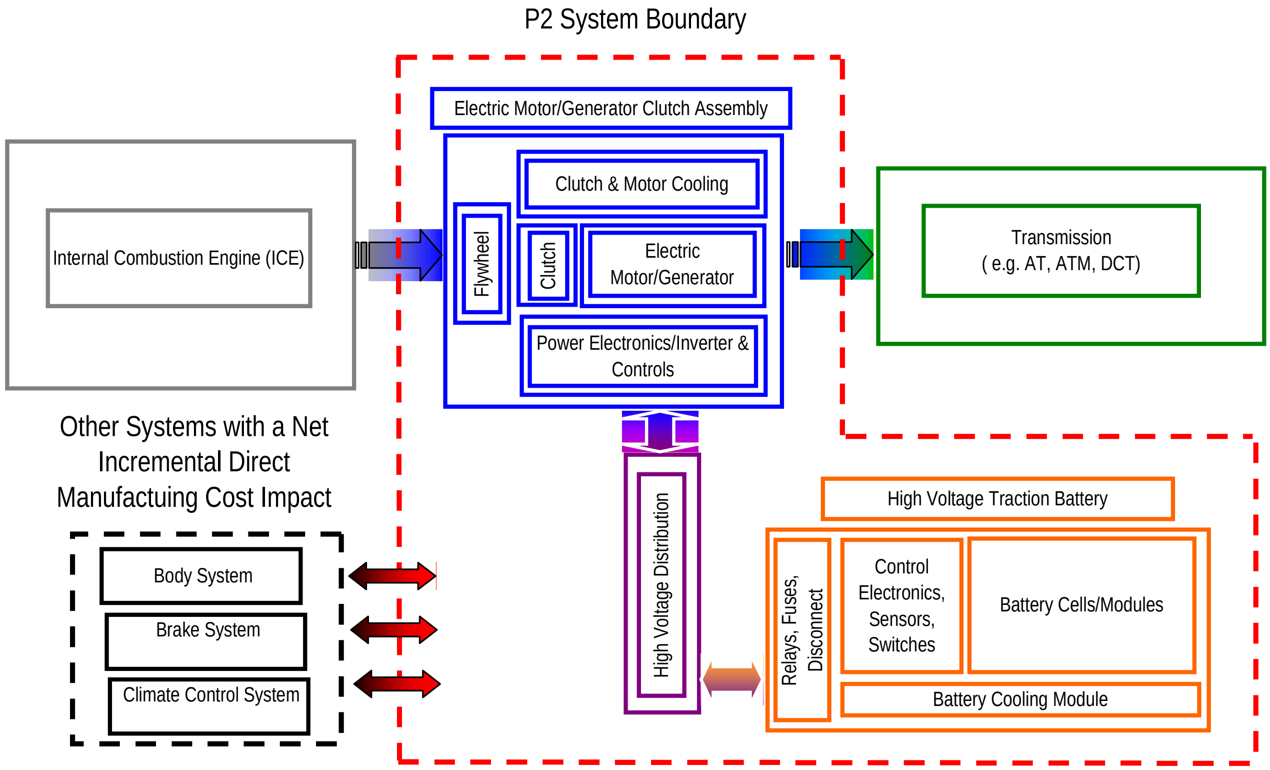


Figure A-3: P2 HEV System Diagram Illustrating Basic Concept Evaluated

For the P2 analysis, a vehicle curb weight reduction was considered for most vehicle segments. Note the mass-reduction considered in the P2 analysis is the result of innovations that are not related to hybridization, such as the shift to lighter material throughout the vehicle. Similar mass-reduction considerations could have been applied to the power-split technology. However, EPA directed FEV to maintain the Fusion characteristics (weight and battery type) in order to keep that result focused on the teardown findings, with minimal extrapolation to other hardware that might find its way into later generation hybrids. For this reason, it would not be appropriate to equivalently compare the power-split and P2 cost results.

The reduction in mass supported a reduction in the net maximum system power and torque, with the exact amount dependent on vehicle segment. The curb weight reductions and corresponding system power reductions are shown in.

Table A-2: P2 Vehicle Segment Mass & Power Reduction Estimates

Vehicle Segment	Mass Reduction	Power Reduction
Subcompact Car	0%	0%
Small/Compact Car	2%	1.8%
Large Car	10%	9.3%
Mini Van	16%	14.9%
Small Truck	16%	14.8%
Large Truck	15%	14.1%

As a result of the lower net system power and torque specification for each vehicle segment, a smaller ICE, integrated traction motor/generator and hydraulic clutch module, high voltage traction battery, and transmission were selected. A further reduction in ICE size was also possible for all vehicle segments, with the exception of large truck, as the electric motor/generator was sized to provide 20% of the net system power (ICE sized to provide 80% of net system power). In the case of the large truck segment, the ICE remained at the net system power requirement and an electric motor/generator was added to provide an addition 20% more power.

Within the scope of this analysis, no consideration was given to selecting a specific ICE or transmission technology configuration, nor was a downsizing credit calculated for either of these two (2) systems. The net incremental direct manufacturing costs, provided in **Table A-3** for each system and vehicle segment evaluated, are representative of adding a P2 HEV system to a conventional powertrain configuration already downsized per the assumptions outlined above (i.e., vehicle mass reduction + assumption ICE can be further reduced as result of electric motor addition).

Table A-3: Net Incremental, Direct Manufacturing Costs for Adding P2 HEV Technology to a Range of Vehicle Segments

System ID	System Description	Calculated Incremental Manufacturing Cost - P2 HEV Technology					
		Sub-Compact Vehicle Segment Passenger 2-4	Small/ Compact Vehicle Segment Passenger 2-5	Large Size/Vehicle Segment Passenger 4-6	Mini Van Vehicle Segment Passenger 6-8	Small Truck	Large Truck
	Vehicle Example	Ford Fiesta	Ford Focus	Ford Fusion and Taurus	Ford Flex	Ford Ranger	Ford Explorer
010000-A	Internal Combustion Engine (ICE) System	Engine technology selection and downsizing outside of analysis scope					-
010000-B	Integrated Electric Motor/Generator and Clutch Assembly System	$ 1,038.80	$ 1,091.51	$ 1,269.82	$ 1,190.83	$ 1,159.44	$ 1,274.14
020000	Transmission System	Transmission technology selection and downsizing outside of analysis scope					-
030000	Body System	$ 6.13	$ 6.25	$ 6.30	$ 6.39	$ 6.25	$ 6.39
060000	Brake System - BBW	$ 225.84	$ 230.74	$ 234.42	$ 235.07	$ 232.78	$ 240.99
120000	Climate Control System	$ 190.72	$ 202.51	$ 217.77	$ 271.48	$ 249.05	$ 239.85
140000	Electric Power Supply System	$ 1,253.72	$ 1,391.21	$ 1,512.44	$ 1,518.78	$ 1,474.39	$ 1,702.71
180000	Power Distribution and Control System	$ 197.11	$ 201.22	$ 203.28	$ 203.97	$ 201.22	$ 212.20
	Net Incremental Direct Manufacturing Cost	$ 2,912.32	$ 3,123.43	$ 3,444.03	$ 3,426.52	$ 3,323.13	$ 3,676.28

Table A-4 and **Table A-5** provide additional cost analysis details for the two major P2 HEV contributing systems (Integrated Electric Motor/Generator and Clutch Assembly System and Electric Power Supply System, respectively).

Table A-4: P2 HEV Integrated Motor/Generator and Clutch Assembly System, Subsystem Cost Analysis Breakdown

System ID	System Description	Calculated Incremental Manufacturing Cost - P2 HEV Technology					
		Sub-Compact Vehicle Segment Passenger 2-4	Small/Compact Vehicle Segment Passenger 2-5	Large Size/Vehicle Segment Passenger 4-6	Mini Van Vehicle Segment Passenger 6-8	Small Truck	Large Truck
	Vehicle Example	Ford Fiesta	Ford Focus	Ford Fusion and Taurus	Ford Flex	Ford Ranger	Ford Explorer
010000-B	Integrated Electric Motor/Generator and Clutch Assembly System (Sum of Subsystems B.1 - B.13)	$ 1,038.80	$ 1,091.51	$ 1,269.82	$ 1,190.83	$ 1,159.44	$ 1,274.14
B.1	Case Subsystem	$ 121.22	$ 129.22	$ 156.84	$ 144.79	$ 138.65	$ 161.75
B.2	Launch Clutch Subsystem	$ 84.87	$ 89.40	$ 104.61	$ 98.86	$ 99.30	$ 114.75
B.3	Oil Pump and Filter Subsystem	$ 29.97	$ 31.71	$ 37.61	$ 35.25	$ 33.97	$ 40.44
B.4	Traction Motor - Generator Subsystem	$ 231.95	$ 242.92	$ 278.58	$ 262.12	$ 253.89	$ 273.09
B.5	Passive Power Electronics Component Subsystem (Capacitors, Filters, etc)	$ 78.52	$ 82.86	$ 96.99	$ 90.47	$ 87.21	$ 94.82
B.6	Power Electronics/Inverter & Controls Subsystem	$ 262.03	$ 271.65	$ 302.91	$ 288.49	$ 281.27	$ 298.11
B.7	Traction Motor-Generator Sensor Subsystem	$ 38.55	$ 38.55	$ 38.55	$ 38.55	$ 38.55	$ 38.55
B.8	Internal Electrical Connection Subsystem	$ 42.11	$ 42.11	$ 42.11	$ 42.11	$ 42.11	$ 42.11
B.9	Switch Subsystem	$ 3.04	$ 3.04	$ 3.04	$ 3.04	$ 3.04	$ 3.04
B.10	Electrical Housing/Support Structure Subsystem	$ 45.40	$ 53.65	$ 80.48	$ 68.10	$ 61.91	$ 76.35
B.11	Electric Motor/Generator & Clutch Cooling Subsystem	$ 46.76	$ 51.80	$ 72.82	$ 64.09	$ 64.73	$ 75.95
B.12	Other Misc (e.g. brackets, sealing, etc)	$ 3.05	$ 3.26	$ 3.96	$ 3.64	$ 3.47	$ 3.85
B.13	OE Electric Motor/Generator Clutch System Assembly	$ 51.33	$ 51.33	$ 51.33	$ 51.33	$ 51.33	$ 51.33

Table A-5: P2 HEV Electric Power Supply System, Subsystem and Component Cost Analysis Breakdown

System ID	System Description	Calculated Incremental Manufacturing Cost - P2 HEV Technology					
		Sub-Compact Vehicle Segment Passenger 2-4	Small/Compact Vehicle Segment Passenger 2-5	Large Size/Vehicle Segment Passenger 4-6	Mini Van Vehicle Segment Passenger 6-8	Small Truck	Large Truck
	Vehicle Example	Ford Fiesta	Ford Focus	Ford Fusion and Taurus	Ford Flex	Ford Ranger	Ford Explorer
H	**Electric Power Supply System**	**$ 1,253.72**	**$ 1,391.21**	**$ 1,512.44**	**$ 1,518.78**	**$ 1,474.39**	**$ 1,702.71**
H.1	Service Battery Subsystem	$ (3.47)	$ (3.47)	$ (3.47)	$ (3.47)	$ (3.47)	$ (3.47)
H.2	Generator/Alternator and Regulator Subsystem	$ (56.92)	$ (61.23)	$ (78.70)	$ (82.72)	$ (82.72)	$ (90.55)
H.3	***High Voltage Traction Battery Subsystem (Li-Polymer)***	***$ 1,202.24***	***$ 1,333.93***	***$ 1,442.29***	***$ 1,442.54***	***$ 1,398.15***	***$ 1,619.13***
H.3.1	Assembly of Battery	$ 21.70	$ 23.19	$ 24.42	$ 24.42	$ 23.93	$ 26.41
H.3.2	Battery Cells/Modules	$ 643.36	$ 737.42	$ 815.17	$ 815.17	$ 783.82	$ 940.58
H.3.3	Relays/Fuses/Disconnects	$ 163.52	$ 163.52	$ 163.52	$ 163.52	$ 163.52	$ 163.52
H.3.4	Internal Wire Harness Connections	$ 31.27	$ 32.93	$ 34.31	$ 34.31	$ 33.76	$ 36.54
H.3.5	Battery Sensing and Control Modules	$ 250.66	$ 274.82	$ 294.79	$ 294.79	$ 286.74	$ 327.00
H.3.6	Battery Cooling Module	$ 45.18	$ 51.79	$ 57.25	$ 57.25	$ 55.05	$ 66.06
H.3.7	Misc Components (e.g. Brackets, Housings, Covers)	$ 14.99	$ 17.18	$ 18.99	$ 18.99	$ 18.26	$ 21.91
H.3.8	Vehicle Interfaces (e.g. Brackets, Wiring, etc)	$ 31.58	$ 33.09	$ 33.84	$ 34.09	$ 33.09	$ 37.11
H.4	Voltage Inverters/Converters Subsystem	$ 111.86	$ 121.98	$ 152.31	$ 162.43	$ 162.43	$ 177.59

B. Introduction

B.1 Objectives

The objective of this work assignment is to determine incremental direct manufacturing costs for a set of advance light-duty vehicle technologies. The technologies selected are on the leading edge for reducing future greenhouse gas emissions, primarily in the form of tailpipe carbon dioxide (CO_2). Such reductions generally correspond to fuel economy improvements. Each technology selected is evaluated against a baseline vehicle technology configuration representative of the current state of vehicle design and similar overall driving performance. To obtain cost results across the diverse light-duty vehicle fleet, application of the new technologies in six (6) vehicle size classes is considered, though no costing was performed for cases in which a technology is not generally considered applicable to a vehicle class. The vehicle size classes are:

- Sub-Compact car: a subcompact car typically powered by a small in-line 4 cylinder engine.
- Small car: a small car typically powered by an in-line 4 cylinder engine
- Large car: a midsize or large passenger car typically powered by a V6 engine
- Minivan: a minivan or large cross-over vehicle with a large frontal area, typically powered by a V6 engine, capable of carrying ~ 6 or more passengers
- Small truck: a small or mid-sized sports-utility or cross-over vehicle, or a small pick-up truck, powered by a large V6 or small V8 engine
- Large truck: large sports-utility vehicles and large pickup trucks, typically powered by a large V8 engine

This report focuses on the incremental costs for two (2) types of advance light-duty vehicle technologies: power-split and P2 hybrid electric vehicle (HEV) technology. Because the basis of the costing methodology is founded on having physical hardware to evaluate, and there were no P2 HEVs available in North America during the time of the analysis, a large size power-split HEV vehicle was chosen for the lead cost analysis. From the lead cost analysis, incremental direct manufacturing costs were developed for other power-split vehicle segments as well as P2 HEV vehicle segments.

For the large size power-split cost analysis (Case Study 0502), a 2010 Ford Fusion HEV was evaluated for content difference relative to a 2010 Ford Fusion vehicle having a conventional powertrain. The Fusion HEV powertrain consisted of a 2.5L Atkinson Cycle I4 engine (156 hp), with two (2) AC synchronous permanent magnet motors (106 hp max. combined), a 275V nickel metal hydride (NiMH) battery (nominal pack capacity 5.5A*hr, 1.51kW*hr), and an electronic continuous variable transmission. The Fusion baseline vehicle utilized a 3.0L V6, Dual Overhead Cam (DOHC), 24 valve engine (240 hp), paired with a 6-speed automatic transmission.

The methodology used to perform the incremental cost analysis was the same as that used in previous studies performed under this work assignment. The vehicles were disassembled to a level where reliable assessments, conducted by the cross-functional team, could be made on hardware differences. Any vehicle components that differed between the HEV and baseline vehicle as a result of the selected powertrain technology configuration were segregated for cost analysis. The selected parts were then disassembled further and costed using standard tools and processes. An overview of teardown and costing analysis is covered in more detail in Section D.

In addition to developing an incremental manufacturing cost for adding power-split HEV technology to a mid- to large-size vehicle, represented by the Ford Fusion in this analysis, calculations for adding this same technology to a range of vehicles segments were also made. In lieu of utilizing full teardowns and cost-ups for each vehicle segment, a scaling methodology was employed. The first step in the process involved defining the size of the primary powertrain system components (e.g., internal combustion engine (ICE), traction motor, generator motor, high voltage battery) for the defined vehicle segment. This was accomplished by utilizing ratios developed within the Ford Fusion analysis (i.e., ICE/traction motor horsepower, traction motor/generator motor horsepower, battery sizing to traction/generator motor sizing, etc.) and applying them to the new vehicle segment to establish primary HEV base component sizes. Once the primary base components were established, component costs within each system were scaled using a variety of parameters including vehicle segment attributes (e.g., vehicle foot print, passenger volume, and curb weight). The scaled totals for each system were then added together to create an estimated vehicle cost. Additional details on the power-split scaling methodology are discussed in Section E.

P2 hybrid incremental direct manufacturing costs were also developed using a similar scaling methodology. Using cost data developed in previous case studies, mainly Ford Fusion HEV power-split analysis and the Hyundai Avante lithium-polymer, a baseline costed bill of materials (BOM) was assembled for a P2 hybrid architecture defined by the EPA. The size of the primary HEV components (i.e., ICE, traction motor, and battery size), for a selected vehicle segment were also selected by the EPA team based on previous studies for such things as weight reduction, improved aerodynamics, and low tire rolling resistance. Using the defined primary HEV components for each vehicle segment, the baseline costed BOM, and parameters developed to scale costs based on select vehicle attributes, P2 incremental direct manufacturing cost were calculated for the six (6) vehicle classes defined previously.

B.2 Process Flow and Key Supporting Documents

The overall process flow is comprised of eleven (11) major steps, described briefly below.

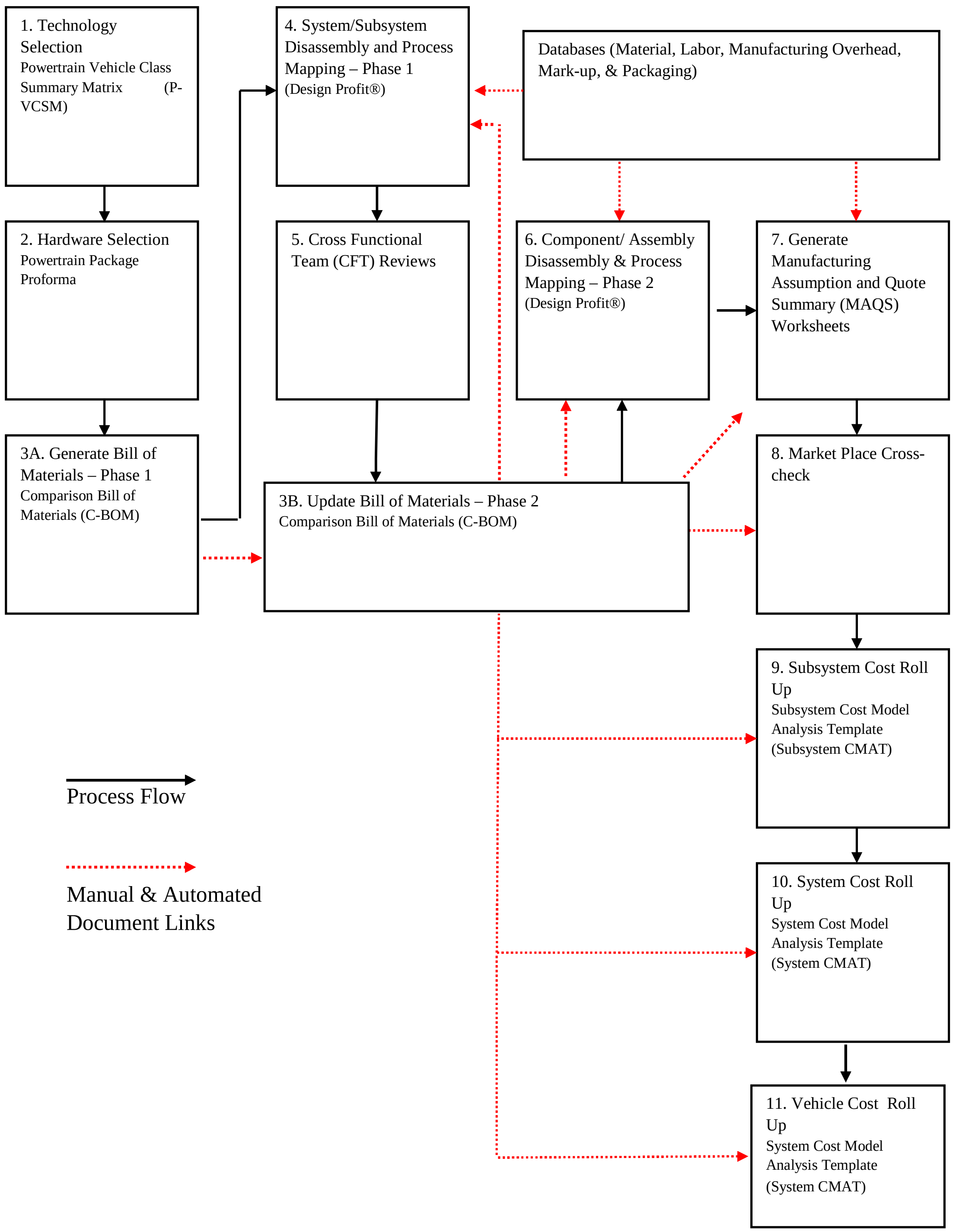


Figure B-1: Cost Analysis Process Flow Steps & Document Interaction

For additional details on these process steps, and the costing methodology in general, please see EPA report EPA-420-R-09-020 “Light-Duty Technology Cost Analysis Pilot Study” (http://www.epa.gov/OMS/climate/420r09020. pdf).

Step 1: Using the Powertrain-Vehicle Class Summary Matrix (P-VCSM) a technology is selected for cost analysis.

Step 2: Existing vehicle models are identified for teardown to provide the basis for detailed incremental cost calculations. The teardown vehicles are chosen in collaboration with EPA to represent the base and new technology cases on the P-VCSM. The vehicle systems involved for many technologies being studied are not extensive, so that entire vehicle need not be torn down or costed out. Instead, engines, transmissions, power supply, power distribution or other major components are targeted. In doing so, close scrutiny is paid to vehicle components that might be indirectly affected by the addition of a new technology, such as those needed for noise, vibration, and harshness (NVH) mitigation. The system and performance details of the selected new and base technology configurations are recorded in the Powertrain Package Proforma.

Step 3: Pre-teardown Comparison Bills of Materials (CBOM) are developed, covering hardware that exists in the new and base technology configurations. These high level CBOMs are informed by the team’s understanding of the new and base technologies and serve to identify the major systems and components targeted for teardown.

Step 4: Phase 1 (high level) teardown is conducted for all systems and subsystems identified in Step 3 and the assemblies that comprise them. Using Design Profit® software, all high level processes (e.g., assemble electronic continuous variable transmission into vehicle, assemble high voltage battery into vehicle) are mapped during the disassembly.

Step 5: A cross-functional team (CFT) reviews all the data generated from the high level teardown. This CFT, with an average relevant experience level of 23 years, employs technology expertise from several areas including: engine and transmission design and development, power electronics, noise, vibration, and harshness (NVH) and driveline subsystems, vehicle integration, production development, manufacturing engineering (supplier and OEM), cost estimating and product benchmarking. Where appropriate, personnel changes are made to the CFT to ensure matching expertise to the technology under analysis.

The CFT captures the assessments in the CBOMs, identifying the component and assembly differences between the new and base technology configurations. All components requiring cost analysis are identified, as well as any base assumptions where applicable (e.g. material selection, primary and secondary manufacturing processes).

<u>Step 6</u>: Phase 2 (component/assembly level) teardowns are done, based on the updated CBOM's. Components and assemblies are disassembled, and processes and operations are mapped in full detail. The process mapping generates key process information for the quote worksheets. Several databases, containing critical costing information, provide support to the mapping process.

<u>Step 7</u>: Manufacturing Assumption and Quote Summary (MAQS) worksheets are generated for all parts undergoing the cost analysis. The MAQS details all cost elements making up the final unit costs:

- material
- labor
- burden
- end item scrap
- selling, general & administrative (SG&A)
- profit
- engineering design & testing (ED&T)
- packaging

In addition, the MAQS worksheet has active links to all key costing parameters.

<u>Step 8</u>: Parts with high or unexpected cost results are subjected to a marketplace cross-check such as comparison with supplier price quotes, or wider consultation with company and industry resources beyond the CFT.

<u>Step 9</u>: All costs calculated in the MAQS worksheets are input automatically into the Subsystem Cost Model Analysis Templates (CMAT) and grouped by sub-subsystems. Some examples of sub-subsystems contained within the high voltage traction battery subsystem include the following: traction battery assembly, traction battery internal wire harness, traction battery sensing and control modules, and traction battery cooling module.

<u>Step 10</u>: The System CMAT is then created, which rolls up all the subsystem differential costs to establish a final system unit cost. For case study #0502, the subsystems in the Electrical Power Supply system included the service battery, generator /alternator and regulator, high voltage traction battery, voltage converter/inverter, and energy management module subsystem.

<u>Step 11</u>: The final step in the process is creating the Vehicle CMAT, which rolls up all the system differential costs to establish a net vehicle incremental cost. For case study #0502, the systems included in the analysis were engine, transmission, body, brake, climate control, power supply and power distribution.

B.3 Cost Analysis Assumptions

When conducting the cost analysis for the various technology configurations, a number of assumptions are made in order to establish a consistent framework for all costing. The assumptions can be broken into universal and specific case study assumptions.

The universal assumptions apply to all technology configurations under analysis. Listed in **Table B-1** are the fundamental assumptions.

The specific case study assumptions are those unique to a given technology configuration. These include volume assumptions, weekly operation assumptions (days, shifts, hours, etc.), packaging assumptions, and Tier 1 in-house manufacturing versus Tier 2/3 purchase part assumptions. Details on the case study specific assumptions can be found in the individual MAQS worksheets.

Table B-1: Summary of Universal Cost Analysis Assumptions Applied to All Case Studies

Item	Description	Universal Case Study Assumptions
1	Incremental **Direct** Manufacturing Costs	A. Incremental **Direct** manufacturing cost is the incremental difference in cost of components and assembly, to the OEM, between the new technology configuration and the baseline technology configuration. B. This value does not include **Indirect** OEM costs associated with adopting the new technology configuration (e.g. tooling, corporate overhead, corporate R&D, etc).
2	Incremental **Indirect** OEM Costs are not handled within the scope of this cost analysis	A. Indirect Costs are handled through the application of "Indirect Cost Multipliers" (ICMs) which are not included as part of this analysis. The ICM covers items such as ..... a. OEM corporate overhead (sales, marketing, warranty, etc) b. OEM engineering, design and testing costs (internal & external) c. OEM owned tooling B. Reference EPA report EPA-420-R-09-003, February 2009, "Automobile Industry Retail Price Equivalent and Indirect Cost Multiplier" for additional details on the develop and application of ICM factors.
3	Product/Technology Maturity Level	A. Mature technology assumption, as defined within this analysis, includes the following: a. Well developed product design b. High production volume c. Products in service for several years at high volumes c. Significant market place competition B. Mature Technology assumption establishes a consistent framework for costing. For example, a defined range of acceptable mark-up rates. a. End-item-scrap 0.3-0.7% b. SG&A/Corporate Overhead 6-7% c. Profit 4-8% d. ED&T (Engineering, Design and Testing) 0-6% C. The technology maturity assumption does not include allowances for product learning. Application of a learning curve to the calculated incremental direct manufacturing cost is handled outside the scope of this analysis.

Item	Description	Universal Case Study Assumptions
4	Selected Manufacturing Processes and Operations	A. All operations and processes are based on existing standard/mainstream Industrial practices. B. No additional allowance is included in the incremental direct manufacturing cost for manufacturing learning. Application of a learning curve to the developed incremental direct manufacturing cost is handled outside the scope of this analysis.
5	Annual Capacity Planning Volume	450,000 Units
6	Supplier Manufacturing Location	North America (USA or Canada)
7	OEM Manufacturing Location	North America (USA or Canada)
8	Manufacturing Cost Structure Timeframe (e.g. Material Costs, Labor Rates, Manufacturing Overhead Rates)	2009/2010 Production Year Rates
9	Packaging Costs	A. Calculated on all Tier One (T1) supplier level components. B. For Tier 2/3 (T2/T3) supplier level components, packaging costs are included in T1 mark-up of incoming T2/T3 incoming goods.
10	Shipping and Handling	A. T1 supplier shipping costs covered through application of the Indirect Cost Multiplier (ICM) discussed above. B. T2/T3 to T1 supplier shipping costs are accounted for via T1 mark-up on incoming T2/T3 goods.
11	Intellectual Property (IP) Cost Considerations	Where applicable IP costs are included in the analysis. Based on the assumption that the technology has reached maturity, sufficient competition would exist suggesting alternative design paths to achieve similar function and performance metrics would be available minimizing any IP cost penalty.
12	Material Cost Reductions (MCRs) on analyzed hardware	Only incorporated on those components where it was evident that the component design and/or selected manufacturing process was chosen due to actual low production volumes (e.g. design choice made to accept high piece price to minimize tooling expense). Under this scenario, assumptions where made, and cost analyzed assuming high production volumes.
13	Operating and End-of Life Costs	No new, or modified, maintenance or end-of-life costs, were identified in the analysis.
14	Stranded Capital or ED&T expenses	No stranded capital or non-recovered ED&T expenses were considered within the scope of this analysis. It was assumed the integration of new technology would be planned and phased in minimizing non-recoverable expenses.

C. Costing Methodology

C.1 Teardown, Process Mapping, and Costing

C.1.1 Cost Methodology Fundamentals

The costing methodology employed in this analysis is based on two (2) primary processes: (1) the development of detailed production process flow charts (P-flows), and (2) the transfer and processing of key information from the P-flows into standardize quoting worksheets. Supporting these two (2) primary processes with key input data are the process cost models and the costing databases (e.g. material [price/lb], labor [$/hour], manufacturing overhead [$/hour], mark-up [% of manufacturing cost], and packaging [$/packaging type]). The costing databases are discussed in greater detail in Section C.4.

Process flow charts, depending on their defined function and the end user, can vary widely in the level of detail contained. They can range from simple block diagrams showing the general steps involved in the manufacturing or assembly of an item, to very detailed process flow charts breaking out each process step in fine detail capturing key manufacturing variables. For this cost analysis, detailed P-flows (which will also be referred to as process maps) are used to identify all the steps involved in manufacturing a product (e.g., assembly, machining, welding, forming), at all levels (e.g., system, subsystem, assembly and component). For example, in a high voltage traction battery scenario, process flows would exist for the following: (1) at the ***component level***, the manufacturing of every component within the battery pack sensing module (unless considered a purchase part); (2) at the ***assembly level***, the assembly of all the individual components to produce the battery pack sensing module; (3) at the ***sub-subsystem level***, the assembly of the battery pack sensing module onto the battery pack; and (4) at the ***subsystem level***, the assembly of the high voltage traction battery into the vehicle. In this example, the high voltage traction battery is one of several subsystems (e.g., service battery subsystem, alternator subsystem, voltage converter-inverter subsystem) making up the electrical power supply system. Each subsystem, if costed in the analysis, would have its own process map broken out using this same process methodology.

In addition to detailing pictorially the process steps involved for a given manufacturing process, having key information (e.g., equipment type, material type and usage, cycle times, handling precautions, number of operators) associated with each step is imperative. Understanding the steps and the key process parameters together creates the costing roadmap for any particular manufacturing process.

Due to the vast and complex nature of P-flows associated with some of the larger systems and subsystems under analysis, having specialized software which can accurately and consistently create and organize the abundant number of detailed P-flows becomes a considerable advantage. For this cost analysis Design Profit® software is utilized for producing and managing the process flows and integrating key costing information.

Simply explained, the symbols which make up the process map each contain essential pieces of information required to develop a cost for a particular operation or process. For example, in a metal stamping process, the basic geometry of the part, quantity and complexity of part features, material gauge thickness, material selection, etc., are examples of the input parameters used in the calculation of the output process parameters (e.g. press size, press cycle time, stamping blank size). From the calculated press size an overhead rate, corresponding to the recommend press size, would be selected from the manufacturing overhead database. Dividing the equipment rate ($/hour) by the cycle time (pieces/hour) yields a manufacturing overhead cost contribution per part. In a similar fashion a labor contribution cost would be generated. The loaded labor rate for a press operator would be pulled from the labor database. An estimate is made on how many presses the operator is overseeing during any given hour of operation. Dividing the labor rate by number of presses the operator is overseeing, and then by number of pieces per hour, a labor cost contribution per part is derived.

Lastly, using the calculated blank size, material type, and material cost (i.e., price per pound) pulled from the materials database, a material contribution cost per part can be calculated. Adding all three cost contributors together (e.g., Manufacturing Overhead, Labor, Material) a Total Manufacturing Cost (TMC) is derived. The TMC is then multiplied by a mark-up factor to arrive at a final manufacturing cost. As explained briefly below and in more detail in Section C.6, key data from the process flows and databases are pulled together in the costing worksheets to calculate the TMC, mark-up contribution, and final manufacturing cost.

There are three (3) basic levels of process parameter models used to convert input parameters into output process parameters that can then be used to calculate operation or processing costs: simple serial, generic moderate, and custom complex. Simple serial are simple process models which can be created directly in Design Profit®. These process models are single input models (e.g., weld time/linear millimeter of weld, cutting time/square millimeter of cross-sectional area, drill time/millimeter of hole depth). Generic moderate process models are more complex than simple serial, requiring multiple input parameters. The models have been developed for more generic types of operations and processes (e.g., injection molding, stamping, diecasting). The process models, developed in Microsoft Excel, are flexible enough to calculate the output parameters for a wide range of parts. Key output parameters, generated from these external process models, are then entered into the process maps. Custom complex parameter models are similar to generic moderate models except in that they are traditionally more complex in nature and have limited usage for work outside of what they were originally developed.

An example of a custom complex model would be one developed for manufacturing a selected size NiMH battery.

All process parameter cost models are developed using a combination of published equipment data, published processing data, actual supplier production data, and/or subject matter expert consultation.

The second major step in the cost analysis process involves taking the key information from the process flows and uploading it into a standardized quote worksheet. The quote worksheet, referred to as the Manufacturing Assumption and Quote Summary (MAQS) worksheet, is essentially a modified generic OEM quoting template. Every assembly included in the cost analysis (excluding commodity purchased parts) has a completed MAQS worksheet capturing all the cost details for the assembly. For example, all the components and their associated costs, required in the manufacturing of a battery pack sensing module assembly, will be captured in battery pack sensing module assembly MAQS worksheet. In addition, a separate MAQS worksheet detailing the cost associated with assembling the battery pack sensing module assembly to the battery pack, along with any other identified high voltage traction battery sub-subsystem components, would be created.

In addition to process flow information feeding into the MAQS worksheet, data is also automatically imported from the various costing databases. More discussion on the MAQS worksheet, interfaces, and complete function is captured in Section C.6.

C.1.2 Serial and Parallel Manufacturing Operations and Processes

For purpose of this analysis, serial operations are defined as operations which must take place in a set sequence, one (1) operation at a time. For example, fixturing metal stamped bracket components before welding can commence, both the fixturing and welding are considered serial operations within the bracket welding process. Conversely, parallel operations are defined as two (2) or more operations which can occur simultaneously on a part. An example of this would be machining multiple features into a cylinder block simultaneously.

A process is defined as one (1) or more operations (serial or parallel) coupled together to create a component, subassembly, or assembly. A serial process is defined as a process where all operations (serial and/or parallel) are completed on a part before work is initiated on the next. For example, turning a check valve body on a single spindle, CNC screw machine, would be considered a serial process. In comparison, a parallel process is where different operations (serial and/or parallel) are taking place simultaneously at multiple stations on more than one (1) part. A multi-station final assembly line, for assembling together the various components of a vacuum pump, would be considered a parallel process.

As discussed, the intent of a process flow chart is to capture all the individual operations and details required to manufacture a part (e.g., component, subassembly, assembly). This often results in a string of serial operations, generating a serial process, which requires additional analysis to develop a mainstream mass production process (i.e., inclusion of parallel operations and processing). The Manufacturing Assumption section of the MAQS worksheet is where the base assumptions for converting serial operations and processes into mass production operations and processes, is captured.

For example, assume "Assembly M" requires fifteen (15) operations to assembly all of its parts. Each operation on average taking approximately ten (10) seconds to complete. In a serial process (analogous to single, standalone work cell, manned by a single operator) consisting of fifteen (15) serial operations, the total process time would be 150 seconds to produce each part (15 operations x 10 second average/station). By taking this serial assembly process and converting it into a mass production parallel process, the following scenarios could be evaluated (Note: rates and assumptions applied below are assumed for this example only):

Scenario #1: 15 serial operation stations, all manned, each performing a single parallel operation.

- Process Time 10 seconds/part, 360 parts/hour @ 100% efficiency
- Labor Cost/Part = [(15 Direct Laborers)*(Labor Rate $30/hour)]/360 parts/hour = $1.25/part
- Burden Cost/Part = [(15 Stations)*(Burden Rate Average (Low Complexity Line) $15/hour/station)]/360 parts/hour = $0.625/part
- Labor + Burden Costs = $1.875/part

Scenario #2: 15 serial operations combined into 10 stations, 5 with 2 parallel automated operations, 5 serial manual operations.

- Process Time 10 seconds/part, 360 parts/hour @ 100% efficiency,
- Labor Cost/Part = [(5 Direct Laborers)*(Labor Rate $30/hour)]/360 parts/hour = $0.42/part
- Burden Cost/Part = [(10 Stations)*(Burden Rate Average (Moderate Complexity Line) $30/hour/station)]/360 parts/hour = $0.83/part
- Labor + Burden Costs = $1.25/part

Assuming a high production volume and a North America manufacturing base (two key study assumptions), Scenario #2 would have been automatically chosen, with the higher level of automation offsetting higher manual assembly costs.

For a component which has a serial process as its typical mass production process (e.g., injection molding, stamping, die casting, selected screw machining), the manufacturing assumption section of the MAQS worksheet requires far less consideration. Analysis is usually limited to determining the total number of equipment pieces required for the defined volume. **Figure C-1** illustrates the fundamental steps incorporated into the cost methodology.

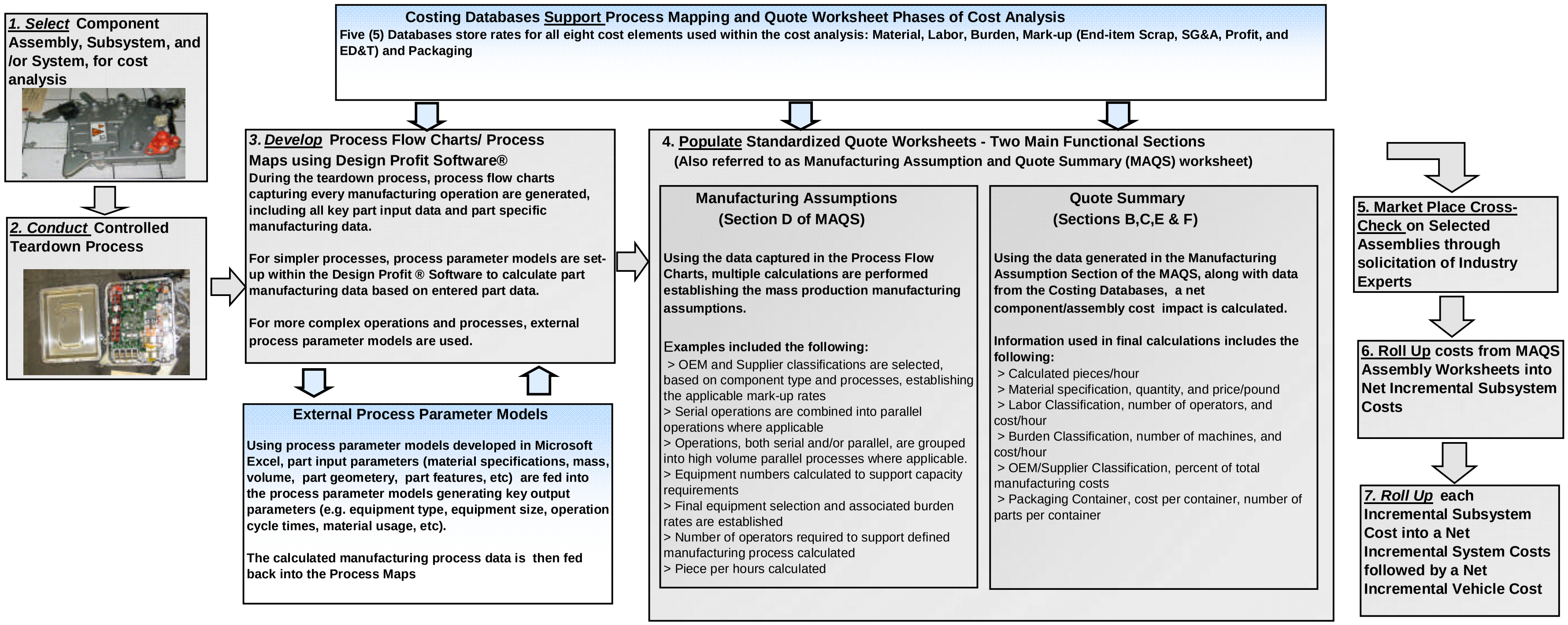


Figure C-1: Fundamental Steps in Costing Process

C.2 Cost Model Overview

The cost parameters considered in determining the net incremental component/assembly impact to the OEM for new technologies are discussed in detail following.

Unit Cost is the sum of total manufacturing cost (TMC), mark-up costs, and packaging cost associated with producing a component/assembly. It is the net component/assembly cost impact to the OEM (generally, the automobile manufacturer). **Figure C-2** shows all the factors contributing to unit cost for supplier manufactured components. Additional details on the subcategories are discussed in the sections that follow.

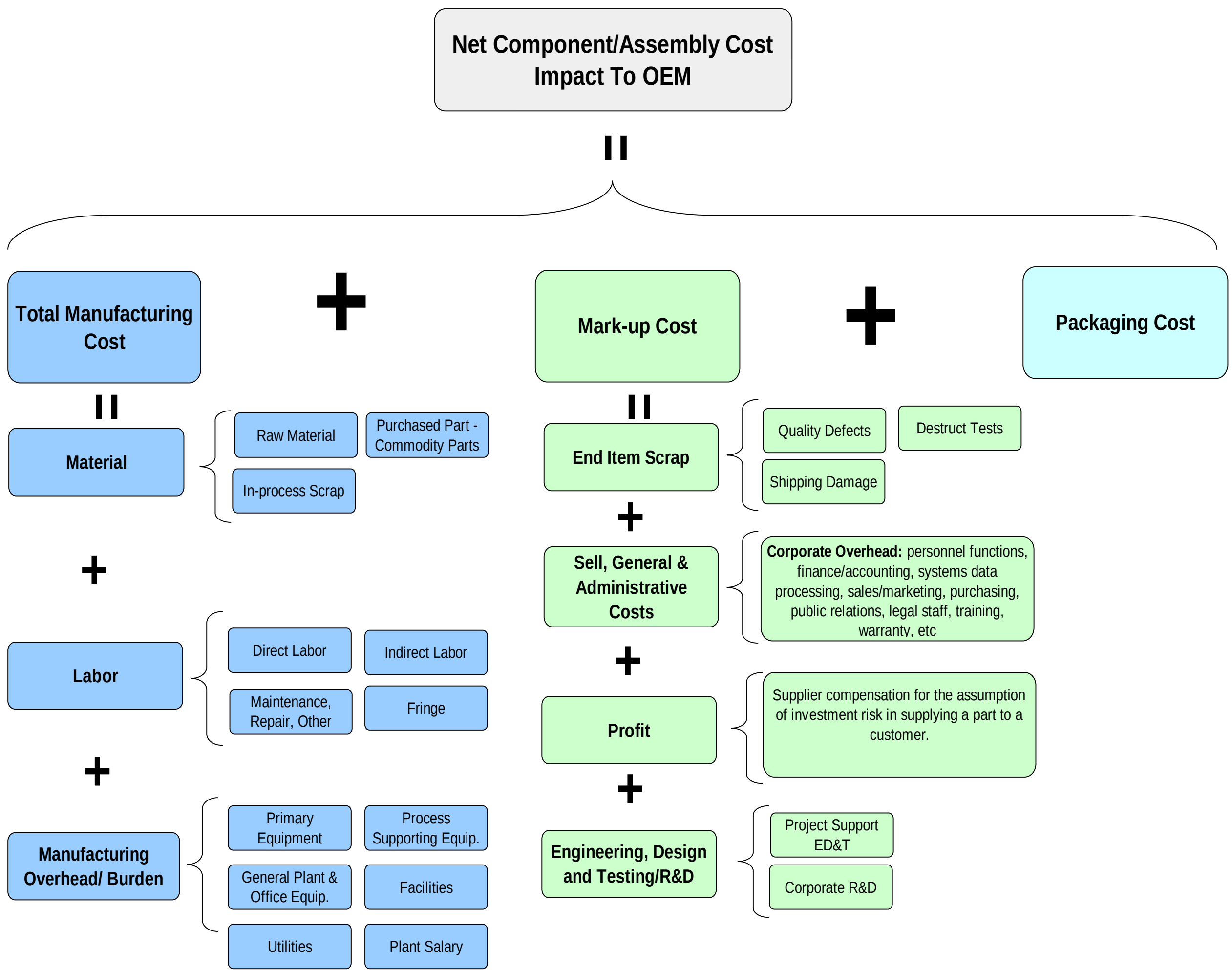


Figure C-2: Unit Cost Model – Costing Factors Included in Analysis

For OEM manufactured components/assemblies, the unit cost is calculated in the same way, except that mark-up is addressed outside the scope of this study through application of indirect cost (IC) multipliers. The IC multiplier assigned is based on the technology complexity level and timeframe in the market place. See Section C.3 for additional details. The full report, "Automobile Industry Retail Price Equivalent and Indirect Cost

Multipliers" EPA report EPA-420-R-09-003, February 2009, can be downloaded from http://www.epa.gov/OMSWWW/ld-hwy/420r09003.pdf.

Shipping Costs are those required to transport a component between dispersed manufacturing and assembly locations, including any applicable insurance, tax, or surcharge expenses. Shipping costs between T2/T3 and T1 suppliers are captured as part of the mark-up rate (except where special handling measures are involved). For T1 supplier to OEM facilities, the shipping costs are captured using the IC multiplier that replaces mark-up as discussed previously. Additional details on shipping costs are discussed in Section C.5.

Tooling Costs are the dedicated tool, gauge, and fixture costs required to manufacture a part. Examples of items covered by tooling costs include injection molds, casting molds, stamping dies, weld fixtures, assembly fixtures, dedicated assembly and/or machining pallets, and dedicated gauging. For this analysis, all tooling is assumed to be owned by the OEM. The differential cost impact is accounted for through the application of an IC multiplier.

Investment Costs are the manufacturing facility costs, not covered as tooling, required to manufacture parts. Investment costs include manufacturing plants, manufacturing equipment (e.g., injection mold machines, die cast machines, machining and turning machines, welding equipment, assembly lines), material handling equipment (e.g., lift forks, overhead cranes, loading dock lifts, conveyor systems), paint lines, plating lines, and heat treat equipment. Investment costs are covered by manufacturing overhead rates and thus are not summed separately in the cost analysis. Additional details on how investments expenses are accounted for through manufacturing overhead can be found in Section C.4.4.

Product Development Costs are the ED&T costs incurred for development of a component or system. These costs can be associated with a vehicle-specific application and/or be part of the normal research and development (R&D) performed by companies to remain competitive. In the cost analysis, the product development costs for suppliers are included in the mark-up rate as ED&T. More details are provided in Section C.4.5. For the OEM, the product development costs are captured in the IC multipliers that replace mark-up, as discussed previously in the Unit Cost section.

In summary, the two (2) main cost elements (TMC and Mark-up) in the supplier unit cost model defined in Figure C-2 include considerations for shipping, investment, and product development costs. Investment costs for the OEM are accounted in the OEM Unit cost model via the TMC. Shipping, tooling, and product development costs are accounted for as part of the IC multiplier addressed outside the scope of this study.

Lastly, the "Net Incremental Direct Manufacturing Cost" is the incremental difference in cost of components and assembly, to the OEM, between the new technology configuration and the baseline technology configuration.

A more detailed discussion on the elements which make-up the unit cost model follows in Section C.4, Costing Databases.

C.3 Indirect OEM Costs

In addition to the direct manufacturing costs, a manufacturer also incurs certain indirect costs. These costs may be related to production, such as research and development (R&D); tooling; corporate operations, such as salaries, pensions, and health care costs for corporate staff; or selling, such as transportation, dealer support, and marketing. Indirect costs incurred by a supplier of a component or vehicle system constitute a direct manufacturing cost to the OEM (the original equipment (vehicle) manufacturer), and thus are included in this study. The OEM's indirect costs, however, are not included and must be determined and applied separately to obtain total manufacturing costs. These indirect costs are beyond the scope of this study and are applied separately by EPA staff in their analysis. The methodology used by EPA to determine indirect costs incurred by auto manufacturers is presented in two (2) studies:

1) Rogozhin, A., et al., "Using Indirect Cost Multipliers to Estimate the Total Cost of Adding New Technology in the Automobile Industry," International Journal of Production Economics (2009), doi:10.1016/j.ijpe.2009.11.031.

2) Gloria Helfand and Todd Sherwood, ''Documentation of the Development of Indirect Cost Multipliers for Three Automotive Technologies,'' Office of Transportation and Air Quality, U.S. EPA, August 2009. This document can be found in the public docket at EPA–HQ–OAR–2010–0799-0064 (www.regulations.gov).

C.4 Costing Databases

C.4.1 Database Overview

The Unit Cost Model shown in **Figure C-2** illustrates the three (3) main cost element categories, along with all the core subcategories, that make up the unit costs for all components and assemblies in the analysis.

Every cost element used throughout the analysis is extracted from one of the core databases. There are databases for material prices ($/pound), labor rates ($/hour), manufacturing overhead rates ($/hour), mark-up rates (% of TMC) and packaging ($/packaging option). The databases provide the foundation of the cost analysis, since all costs originate from them, and they are also used to document sources and supporting information for the cost numbers.

The model allows for updates to the cost elements which automatically roll into the individual component/assembly cost models. Since all cost sheets and parameters are directly linked to the databases, changing the “Active Rate” cost elements in the applicable database automatically updates the Manufacturing Assumption Quote Summary (MAQS) worksheets. Thus, if a material doubles in price, one can easily assess the impact on the technology configurations under study.

C.4.2 Material Database

C.4.2.1 Overview

The Material Database houses specific material prices and related material information required for component cost estimating analysis. The information related to each material listed includes the material name, standard industry identification (e.g., AISI or SAE nomenclature), typical automotive applications, pricing per pound, annual consumption rates, and source references. The prices recorded in the database are in US dollars per pound.

C.4.2.2 Material Selection Process

The materials listed in the database (resins, ferrous, and non-ferrous alloys) are used in the products and components selected for cost analysis. The materials identification process is based on visual part markings, part appearance, and part application. Material markings are the most obvious method of material identification. Resin components typically have material markings (e.g., >PA66 30GF<) which are easily identified, recorded in the database, and researched to establish price trends.

For components which are not marked, such as transmission gears, battery casings, battery electrodes, motor stator plates, and the like, the FEV and Munro cross-functional team members are consulted in the materials identification. For any materials still not identified, information published in print and on the web is researched, or primary manufacturers and experts within the Tier 1 supplier community are contacted to establish credible material choices.

The specific application and the part appearance play a role in materials identification. Steels commonly referred to as work-hardenable steels with high manganese content (13% Mn) are readily made in a casting and are not forgeable. Therefore, establishing whether a component is forged or cast can narrow the materials identification process. Observing visual cues on components can be very informative. Complex part geometry alone can rule out the possibility of forgings; however, more subtle differences must be considered. For example, forged components typically have a smoother appearance to the grain whereas cast components have a rougher finish, especially in the areas where machining is absent. Castings also usually display evidence of casting flash.

The component application environment will also help determine material choice. There are, for example, several conventional ductile cast iron applications found in base gasoline engines that are moving to Ductile High Silicon - Molybdenum or Ductile Ni-Resist cast irons in downsized turbocharged engines. This is due to high temperature, thermal cycling, and corrosion resistance demands associated with elevated exhaust gas temperatures in turbocharged engines. Therefore, understanding the part application and use environment can greatly assist in more accurate material determinations.

C.4.2.3 Pricing Sources and Considerations

The pricing data housed in the database is derived from various sources of publicly available data from which historical trend data can be derived. The objective is to find historical pricing data over as many years as possible to obtain the most accurate trend response. Ferrous and non-ferrous alloy pricing involves internet searches of several sources, including the U.S. Geological Survey (USGS), MEPS (previously Management Engineering & Production Services), Metalprices, estainlesssteel and Longbow.

Resin pricing is also obtained from sources such as Plastics News, Plastics Technology Online, Rubber and Plastics News, and IDES (Integrated Design Engineering Systems). Several other sources are used in this research as outlined in the database.

Though material prices are often published for standard materials, prices for specialized material formulations and/or those having a nonstandard geometric configuration (e.g., length, width, thickness, cross-section), are not typically available. Where pricing is not available for a given material with a known composition, two (2) approaches are used: industry consultation and composition analysis.

Industry consultation mainly takes the form of discussions with subject matter experts familiar with the material selection and pricing used in the products under evaluation to acquiring formal quotes from raw material suppliers. For example, in the case of the NiMH battery, much of the material pricing was acquired from supplier quotes at the capacity planning volumes stated in the analysis.

In those cases where published pricing data was unavailable and raw material supplier quotes could not be acquired, a composition analysis was used. This was achieved by building prices based on element composition and applying a processing factor (i.e., market price/material composition cost) derived from a material within the same material family. The calculated price was compared to other materials in the same family as a means to ensure the calculated material price was directionally correct.

Obtaining prices for unknown proprietary material compositions, such as powder metals, necessitated a standardized industry approach. In these cases, manufacturers and industry market research firms are consulted to provide generic pricing formulas and pricing trends. Their price formulas are balanced against published market trends of similar materials to establish new pricing trends.

Resin formulations are also available with a variety of fillers and filler content. Some pricing data is available for specific formulations; however, pricing is not published for every variation. This variation is significant since many manufacturers can easily tailor resin filler type and content to serve the specific application. Consequently, the database has been structured to group resins with a common filler into ranges of filler content. For example, glass filled Nylon 6 is grouped into three (3) categories: 0 to 15 percent glass filled, 30 to 35 percent glass filled, and 50 percent glass filled, each with their own price point. These groupings provide a single price point as the price differential within a group (0 to 15 percent glass filled) is not statistically significant

C.4.2.4 In-process Scrap

In-process scrap is defined as the raw material mass, beyond the final part weight, required to manufacture a component. For example, in an injection molded part, the in-process scrap is typically created from the delivery system of the molten plastic into the part cavity (e.g., sprue, runners and part gate). This additional material is trimmed off following part injection from the mold. In some cases, dependent on the material and application, a portion of this material can be ground up and returned into the virgin material mix.

In the case of screw machine parts, the in-process scrap is defined as the amount of material removed from the raw bar stock in the process of creating the part features. Generally, material removed during the various machining processes is sold at scrap value. Within this cost analysis study, no considerations were made to account for recovering scrap costs.

A second scrap parameter accounted for in the cost analysis is end-item scrap. End-item scrap is captured as a cost element within mark-up and will be discussed in more detail within the mark-up database section, Section C.4.5. Although it is worth reiterating here that in-process scrap only covers the additional raw material mass required for manufacturing a part, it does not include an allowance for quality defects, rework costs and/or destructive test parts. These costs are covered by the end-item scrap allowance.

C.4.2.5 Purchase Parts – Commodity Parts

In the quote assumption section of the CBOM, parts are identified as either "make" or "buy." The "make" classification indicates a detailed quote is required for the applicable part, while “buy” indicates an established price based on historical data is used in place of a full quote work-up. Parts identified as a “buy” are treated as a purchased part.

Many of the parts considered to be purchased are simple standard fasteners (nuts, bolts, screws, washers, clips, hose clamps) and seals (gaskets, o-rings). However, in certain cases, more value-added components are considered purchased when sufficient data existed supporting their cost as a commodity: that is, where competitive or other forces drive these costs to levels on the order of those expected had these parts been analyzed as “make” parts.

In the MAQS worksheet, standard purchase parts costs are binned to material costs, which, in the scope of this analysis, are generally understood to be raw material costs. If the purchase part content for a particular assembly or system is high in dollar value, the calculated cost breakdown in the relevant elements (i.e., material, labor, manufacturing overhead, mark-up) tended to be misleading. That is the material content would show artificially inflated because of the high dollar value of purchase part content.

To try and minimize this cost binning error, purchase parts with a value in the range of $10 to $15, or greater, were broken into the standard cost elements using cost element ratios developed for surrogate type parts. For example, assume a detailed cost analysis is conducted on a linear inductive position sensor, “Sensor A.” The ratio of material, labor, manufacturing overhead, and mark-up, as a percent of the selling price, can easily be calculated. Knowing the commodity selling price for a similar type of inductive sensor, “Sensor B,” along with the cost element ratios developed for Sensor A, estimates can be made on the material, labor, manufacturing overhead, and mark-up costs for Sensor B.

Purchased part costs are obtained from a variety of sources. These include FEV and Munro team members’ cost knowledge, surrogate component costing databases, Tier 1 supplier networks, published information, and service part cost information. Although an important component of the overall costing methodology, purchase part costs are used judiciously and conservatively, primarily for mature commodity parts.

C.4.3 Labor Database

C.4.3.1 Overview

The Labor Database contains all the standard occupations and associated labor rates required to manufacture automotive parts and vehicles. All labor rates referenced throughout the cost analysis are referenced from the established Labor Database.

Hourly wage rate data used throughout the study, with exception of fringe and wage projection parameters, is acquired from the Bureau of Labor Statistics (BLS). For the analysis, mean hourly wage rates were chosen for each occupation, representing an average wage across the United States.

The Labor Database is broken into two (2) primary industry sections, Motor Vehicle Parts Manufacturing (supplier base) and Motor Vehicle Manufacturing (OEMs). These two (2) industry sections correspond to the BLS, North American Industry Classification System (NAICS) 336300 and 336100 respectively. Within each industry section of the database, there is a list of standard production occupations taken from the BLS Standard Occupation Classification (SOC) system. For reference, the base SOC code for production occupations within the Motor Vehicle Parts Manufacturing and Motor Vehicle Manufacturing is 51-0000. Every production occupation listed in the Labor Database has a calculated labor rate, as discussed in more detail below. For the midsize power-split HEV case study (#0502), 2009 rates were used.

C.4.3.2 Direct Versus Total Labor, Wage Versus Rate

Each standard production occupation found in the Labor Database has an SOC identification number, title, labor description, and mean hourly wage taken directly from the BLS.

Only "direct" production occupations are listed in the labor database. Team assemblers and forging, cutting, punching, and press machine operators are all considered direct production occupations. There are several tiers of manufacturing personnel supporting the direct laborers that need to be accounted for in the total labor costs, such as quality technicians, process engineers, lift truck drivers, millwrights, and electricians. A method typically used by the automotive industry to account for all of these additional "indirect labor" costs – and the one chosen for this cost analysis – is to calculate the contribution of indirect labor as an average percent of direct labor, for a given production occupation, in a given industry sector.

The BLS Database provides labor wage data, rather than labor rate data. In addition to what a direct laborer is paid, there are several additional expenses the employer must cover in addition to the employee base wage. This analysis refers to these added employer expenditures as "fringe". Fringe is applicable to all employees and will be discussed in greater detail following.

It should be noted that the BLS motor vehicle and motor vehicle parts manufacturing (NAICS 336100 & 336300) labor rates include union and non-union labor rates, reflecting the relative mix of each in the workforce at the time the data was gathered (2009).

C.4.3.3 Contributors to Labor Rate and Labor Rate Equation

The four (4) contributors to labor costs used in this study are:

Direct Labor (DIR) is the ***mean*** manufacturing labor wage directly associated with fabricating, finishing, and/or assembling a physical component or assembly. Examples falling into this labor classification include injection mold press operators, die cast press operators, heat treat equipment operators, team/general assemblers, computer numerical controlled (CNC) machine operators, and stamping press operators. The median labor wage for each direct labor title is also included in the database. These values are treated as reference only.

Indirect Labor (IND) is the manufacturing labor indirectly associated with making a physical component or assembly. Examples include material handling personnel, shipping and receiving personnel, quality control technicians, first-line supervisors, and manufacturing/process engineers. For a selected industry sector (such as injection molding, permanent casting, or metal stamping), an average ratio of indirect to direct labor costs can be derived from which the contribution of indirect labor ($/hour) can be calculated.

This ratio is calculated as follows:

1. An industry sector is chosen from the BLS, NAIC System. (e.g., Plastics Product Manufacturing NAICS 326100).
2. Within the selected industry sector, occupations are sorted (using SOC codes) into one (1) of the four (4) categories: Direct Labor, Indirect Labor, MRO Labor, or Other.
3. For each category (excluding “Other”) a total cost/hour is calculated by summing up the population weighted cost per hour rates, for the SOC codes within each labor category.
4. Dividing the total indirect labor costs by total direct labor costs, the industry sector ratio is calculated.
5. When multiple industries employ the same type direct laborer, as defined by NAICS, a weighted average of indirect to direct is calculated using the top three (3) industries.

Maintenance Repair and Other (MRO) is the labor required to repair and maintain manufacturing equipment and tools ***directly*** associated with manufacturing a given component or assembly. Examples falling into this labor classification include electricians, pipe fitters, millwrights, and on-site tool and die tradesmen. Similar to indirect labor, an average ratio of MRO to direct labor costs can be derived from which the contribution of MRO labor ($/hour) can be calculated. The same process used to calculate the indirect labor ratio is also used for the MRO ratio.

Fringe (FR) is all the additional expenses a company must pay for an employee above and beyond base wage. Examples of expenses captured as part of fringe include company medical and insurance benefits, pension/retirement benefits, government directed benefits, vacation and holiday benefits, shift premiums, and training.

Fringe applies to all manufacturing employees. Therefore the contribution of fringe to the overall labor rate is based on a percentage of direct, indirect and MRO labor. Two (2) fringe rates are used: 52% for supplier manufacturing, and 160% for OEM manufacturing. The supplier manufacturing fringe rate is based on data acquired from the BLS (Table 1009: Manufacturing Employer Costs for Employee Compensation Per Hours Worked: 2000-2010). Taking an average of the “Total Compensation” divided by “Wages and Salaries” for manufacturing years 2008 thru 2010, an average fringe rate of 52% was calculated.

Due to the dynamic change of OEM wage and benefit packages over the last few years (2008-2010), and differences among the OEMs, no updates were made from the original OEM fringe assumptions developed for the initial “Light-Duty Technology Cost Analysis Pilot Study” EPA-420-R-09-020 (http://www.epa.gov/OMS/climate/420r09020. pdf). The OEM fringe rate utilized throughout the analysis was 160%.

C.4.4 Manufacturing Overhead Database

C.4.4.1 Overview

The Manufacturing Overhead Database contains several manufacturing overhead rates (also sometimes referred to as “burden rates,” or simply “burden”) associated with various types of manufacturing equipment, that are required to manufacture automotive parts and vehicles. With material and labor costs it forms the total manufacturing cost (TMC) to manufacture a component or assembly, and, subsequently, the cost accounting for considerations such as workers, supervisors, managers, raw materials, purchased parts, production facilities, fabrication equipment, finishing equipment, assembly equipment, utilities, measurement and test equipment, handling equipment, and office equipment. Manufacturing equipment is typically one of the largest contributors to manufacturing overhead, so manufacturing overhead rates are categorized according to primary manufacturing processes and the associated equipment as follows:

1. The first tier of the Manufacturing Overhead Database is arranged by the primary manufacturing process groups (e.g., thermoplastic molding, thermoset molding, castings, forgings, stamping and forming, powder metal, machining, turning, etc.)
2. The second tier subdivides the primary manufacturing process groups into primary processing equipment groups. For example the ‘turning group’ consists of several subgroups including some of the following: (1) CNC turning, auto bar fed, dual axis machining, (2) CNC turning, auto bar fed, quad axis machining, (3) double-

sided part, CNC turning, auto bar fed, dual axis machining, and (4) double-sided part, CNC turning, auto bar fed, quad axis machining.

3. The third and final tier of the database increases the resolution of the primary processing equipment groups and defines the applicable manufacturing overhead rates. For example, within the “CNC turning, auto bar fed, dual axis machining” primary process equipment group, there are four (4) available machines sizes (based on max cutting diameter and part length) from which to choose. The added resolution is typically based on part size and complexity and the need for particular models/versions of primary and secondary processing equipment.

C.4.4.2 Manufacturing Overhead Rate Contributors and Calculations

In this analysis burden is defined in terms of an “inclusion/exclusion” list as follows:

Burden costs **do not** include:

- manufacturing material costs
- manufacturing labor costs
    - direct labor
    - indirect labor
    - maintenance repair and other (MRO) labor
- mark-up
    - end-item scrap
    - corporate SG&A expenses
    - profit
    - ED&T/ R&D costs expenses
- tooling (e.g., mold, dies, gauges, fixtures, dedicated pallets)
- packaging costs
- shipping and handling costs

Burden costs **do** include:

- rented and leased equipment
- primary and process support manufacturing equipment depreciation
- plant office equipment depreciation
- utilities expense
- insurance (fire and general)
- municipal taxes
- plant floor space (equipment and plant offices)
- maintenance of manufacturing equipment (non-labor)
- maintenance of manufacturing building (general, internal and external, parts, and labor)

- operating supplies
- perishable and supplier-owned tooling
- all other plant wages (excluding direct, indirect and MRO labor)
- returnable dunnage maintenance (includes allowance for cleaning and repair)
- intra-company shipping costs

As shown in the lists above, burden includes both fixed and variable costs. Generally, the largest contribution to the fixed burden costs are the investments associated with primary and process support equipment. The single largest contributor to the variable burden rate is typically utility usage.

C.4.4.3 Acquiring Manufacturing Overhead Data

Because there is very limited publicly available data on manufacturing overhead rates for the industry sectors included in this analysis, overhead rates have been developed from a combination of internal knowledge at FEV and Munro, supplier networks, miscellaneous publications, reverse costing exercises, and "ground-up" manufacturing overhead calculations.

For ground-up calculations, a generic "Manufacturing Overhead Calculator Template" was created. The template consists of eight (8) sections:

- General Manufacturing Overhead Information
- Primary Process Equipment
- Process Support Equipment
- General Plant & Office Hardware/Equipment
- Facilities Cost
- Utilities
- Plant Salaries
- Calculated Hourly Burden Rate.

The hourly burden rate calculation for a 500 ton (T) injection mold machine is used as an example in the following paragraphs. The General Manufacturing Overhead Information section, in addition to defining the burden title (Injection Molding, Medium Size and/or Moderate Complexity) and description (Injection Molding Station, 500T Press), also defines the equipment life expectancy (12 years), yearly operating capacity (4,700 hours), operation efficiency (85%), equipment utilization (81.99%) and borrowing cost of money (8%). These input variables support many of the calculations made throughout the costing template.

The Primary Process Equipment section (500T Horizontal Injection Molding Machine) calculates the annual expense ($53,139) associated with equipment depreciation over the defined life expectancy. A straight-line-depreciation method, with zero end of life value, is assumed for all equipment. Included in the cost of the base equipment are several factors such as sales tax, freight, installation, and insurance. In addition, a maintenance, repair and other (MRO) expense (other than MRO labor, which is covered as part of the overall labor cost), calculated as a percentage of the primary process equipment cost, is included in the development of the manufacturing overhead.

The Process Support Equipment section (e.g., Chiller, Dryer, Thermal Control Unit-Mold), similar to the Primary Process Equipment section, calculates the annual expense ($6,121) associated with process support equipment depreciation.

The General Plant and Office Hardware/Equipment section assigns an annual contribution directed toward covering a portion of the miscellaneous plant & office hardware/equipment costs (e.g., millwright, electrician, and plumbing tool crib, production/quality communication, data tracking and storage, general material handling equipment, storage, shipping and receiving equipment, general quality lab equipment, office equipment). The contribution expense ($2,607) is calculated as a percent of the annual primary and process support equipment depreciation costs.

The Facilities Cost section assigns a cost based on square footage utilization for the primary equipment ($4,807), process support equipment ($3,692), and general plant and office hardware/equipment ($6,374). The general plant and office hardware/equipment floor space allocation is a calculated percentage (default 75%) of the derived primary and process support equipment floor space. The expense per square foot is $11.50 and covers several cost categories such as facility depreciation costs, property taxes, property insurance, general facility maintenance, and general utilities.

The Utilities section calculates a utility expense per hour for both primary equipment ($9.29/hour) and process support equipment ($3.51/hour) based on equipment utility usage specifications. Some of the utility categories covered in this section include: electricity at $0.10/kW-hr, natural gas at $0.00664/cubic foot, and water at $0.001/gallon. General plant and office hardware/equipment utility expenses are covered as part of the facility cost addressed in the paragraph above (i.e., $11.50/square foot).

The Plant Salary section estimates the contribution of manufacturing salaries (e.g., plant manager, production manager, quality assurance manager) assigned to the indirect participation of primary and process support equipment. An estimate is made on the average size of the manufacturing facility for this type of primary process equipment. There are six (6) established manufacturing facility sizes and corresponding salary payrolls. Each has a calculated salary cost/square foot. Based on the combined square footage utilization of the primary, process support, and general plant and office equipment, an annual salary contribution cost is calculated ($6,625).

The final section, Calculated Hourly Burden Rate, takes the calculated values from the previous sections and calculates the hourly burden rate in three (3) steps: (1) 100% efficiency and utilization ($30.54/hour); (2) user-defined efficiency with 100% utilization ($35.12/hour); and (3) both user-defined efficiency and utilization ($38.79/hour).

The majority of primary process equipment groups (e.g., injection molding, aluminum die casting, forging, stamping and forming) in the manufacturing overhead database are broken into five (5) to ten (10) burden rate subcategories based on processing complexity and/or size, as discussed in the manufacturing overhead review. For any given category, there will often be a range of equipment sizes and associated burden rates which are averaged into a final burden rate. The goal of this averaging method is to keep the database compact while maintaining high costing resolution.

In the example of the 500T injection molding press burden rate, the calculated rate ($38.79) was averaged with three (3) other calculated rates (for 390T, 610T and 720T injection mold presses) into a final burden rate called "Injection Molding, Medium Size and/or Moderate Complexity." The final calculated burden rate of $50.58/hour is used in applications requiring injection molding presses in the range of 400-800 tons.

The sample calculation of the manufacturing overhead rate for an injection molding machine above is a simple example highlighting the steps and parameters involved in calculating overhead rates. Regardless of the complexity of the operation or process, the same methodology is employed when developing overhead rates.

As discussed, multiple methods of arriving at burden rates are used within the cost analysis. Every attempt is made to acquire multiple data points for a given burden rate as a means of validating the rate. In some cases, the validation is accomplished at the final rate level and in other cases multiple pieces of input data, used in the calculation of a rate, are acquired as a means of validation.

C.4.5 Mark-up (Scrap, SG&A, Profit, ED&T)

C.4.5.1 Overview

All mark-up rates for Tier 1 and Tier 2/3 automotive suppliers referenced throughout the cost analysis can be found in the Mark-up Database, except in those cases where unique component tolerances, performance requirements, or some other unique feature dictates a special rate. In cases where a mark-up rate is "flagged" within the costing worksheet, a note is included which describes the assumption differences justifying the modified rate.

For this cost analysis study, four (4) mark-up sub-categories are used in determining an overall mark-up rate: (1) end-item scrap allowance, (2) SG&A expenses, (3) profit, and (4) ED&T/R&D expenses. Additional details for each subcategory are discussed following.

The layout of the Mark-up Database is similar to the Manufacturing Overhead Database in that the first tier of the Mark-up Database is arranged by the primary manufacturing process groups (e.g., thermoplastic processing, thermoset processing, casting, etc.). The second tier subdivides the primary manufacturing process groups into primary processing equipment groups (e.g., thermoplastic processing is subdivided into injection molding, blow or rotational molding, and pressure or vacuum form molding). The third and final tier of the database increases the resolution of the primary processing equipment groups and defines the applicable mark-up rates. Similar to the overhead manufacturing rates, size and complexity of the parts being manufactured will direct the process and equipment requirements, as well as investments. This, in turn, will have a direct correlation to mark-up rates.

C.4.5.2 Mark-up Rate Contributors and Calculations

Mark-up, in general, is an added allowance to the Total Manufacturing Cost to cover end-item scrap, SG&A, profit and ED&T expenses. The following are additional details on what is included in each mark-up category:

End-Item Scrap Mark-up is an added allowance to cover the projected manufacturing fall-out and/or rework costs associated with producing a particular component or assembly. In addition, any costs associated with in-process destructive testing of a component or assembly are covered by this allowance. As a starting point, scrap allowances were estimated to be between 0.3% and 0.7% of the TMC within each primary manufacturing processing group The actual assigned value for each category is an estimate based on size and complexity of the primary processing equipment as shown in **Table C-1**.

When published industry data or consultation with an industry expert improves estimate accuracy for scrap allowance associated with a generic manufacturing process (e.g., 5% for sand casting, investment casting), the Mark-up Database is updated accordingly. In cases where the manufacturing process is considered generic, but the component performance requirements drive a higher fall-out rate (e.g., 25% combined process fallout on turbocharger turbine wheels), then the scrap mark-up rate would only be adjusted in the Manufacturing Assumption Quote Summary (MAQS) worksheet.

Selling, General, and Administrative (SG&A) Mark-up is also referred to as corporate overhead or non-manufacturing overhead costs. Some of the more common cost elements of SG&A are:

- Non-manufacturing, corporate facilities (building, office equipment, utilities, maintenance expenses, etc.)
- Corporate salaries (President, Chief Executive Officers, Chief Financial Officers, Vice Presidents, Directors, Corporate Manufacturing, Logistics, Purchasing, Accounting, Quality, Sales, etc.)
- Insurance on non-manufacturing buildings and equipment
- Legal and public relation expenses
- Recall insurance and warranty expenses
- Patent fees
- Marketing and advertising expenses
- Corporate travel expenses

SG&A, like all mark-up rates, is an applied percentage to the Total Manufacturing Cost. The default rates for this cost analysis range from 6% to 7% within each of the primary processing groups. The actual values, as with the end-item scrap allowances, vary within these ranges based on the size and complexity of the part, which in turn is reflected in the size and complexity of the processing equipment as shown in **Table C-1**. To support the estimated SG&A rates (which are based on generalized OEM data), SG&A values are extracted from publicly traded automotive supplier 10-K reports.

Profit Mark-up is the supplier's or OEM's reward for the investment risk associated with taking on a project. On average, the higher the investment risk, the larger the profit mark-up that is sought by a manufacturer.

As part of the assumptions list made for this cost analysis, it is assumed that the technology being studied is mature from the development and competition standpoint. These assumptions are reflected in the conservative profit mark-up rates which range from 4% to 8% of the Total Manufacturing Cost. The profit mark-up ranges selected from this cost analysis are based on generalized historical data from OEMs and suppliers.

As detailed with the preceding mark-up rates, the actual assigned percentage is based on the supplier processing equipment size and complexity capabilities (**Figure C-2**).

ED&T Mark-up: the ED&T used for this cost analysis is a combination of "Traditional ED&T" plus R&D mark-up.

Traditional ED&T may be defined as the engineering, design and testing activities required to take an "implementation ready" technology and integrate it into a specific vehicle application. The ED&T calculation is typically more straight-forward because the tasks are predefined. R&D, defined as the cost of the research and development activities required to create a new (or enhance an existing) component/system technology, is often independent of a specific vehicle application. In contrast to ED&T, pure R&D costs are very difficult to predict and are very risky from an OEM and suppliers perspective, in that these costs may or may not result in a profitable outcome.

For many automotive suppliers and OEMs, traditional ED&T and R&D are combined into one (1) cost center. For this cost analysis, the same methodology has been adopted, creating a combined traditional ED&T and R&D mark-up rate simply referred to as ED&T.

Royalty fees, as the result of employing intellectual property, are also captured in the ED&T mark-up section. When such cases exist, separate lines in the Manufacturing Assumption & Quote Summary (MAQS) worksheet are used to capture these costs. These costs are in addition to the standard ED&T rates. The calculation of the royalty fees are on a case by case basis and information regarding the calculation of each fee can be found in the individual MAQS worksheets where applicable.

Table C-1: Standard Mark-up Rates Applied to Tier 1 and Tier 2/3 Suppliers Based on Size and Complexity Ratings

Primary Manufacturing Equipment Group	End Item Scrap Mark-up	SG&A Mark-up	Profit Mark-up	ED&T Mark-up	Total Mark-up
Tier 2 /3 – Large Size, High Complexity,	0.7%	7.0%	8.0%	2.0%	17.7%
Tier 2 /3 – Medium Size, Moderate Complexity,	0.5%	6.5%	6.0%	1.0%	14.0%
Tier 2 /3 – Small Size, Low Complexity	0.3%	6.0%	4.0%	0.0%	10.3%
Tier 1 Complete System/Subsystem Supplier (System/Subsystem Integrator)	0.7%	7.0%	8.0%	6.0%	21.7%
T1 High Complexity Component Supplier	0.7%	7.0%	8.0%	4.0%	19.7%
T1 Moderate Complexity Component Supplier	0.5%	6.5%	6.0%	2.5%	15.5%
T1 Low Complexity Component Supplier	0.3%	6.0%	4.0%	1.0%	11.3%

C.4.5.3 Assigning Mark-up Rates

The three (3) primary steps to matching mark-up rates to a given component are:

> **<u>Step 1</u>:** Primary manufacturing process and equipment groupings are pre-selected as part of the process to identify the manufacturing overhead rate.
>
> **<u>Step 2</u>:** Manufacturing facilities are identified as OEM, T1 or T2/T3 (this identification process is discussed in more detail in the Manufacturing Assumption & Quote Summary worksheet section).
>
> **<u>Step 3</u>:** The best-fit mark-up rate is selected based on the size and complexity of the part, which in turn is reflected in the size and complexity of the processing equipment. Note that size and complexity are considered as independent parameters when reviewing a component and the equipment capabilities (with priority typically given to "complexity").

Further details on methodology for developing TMC and mark-up can be found in EPA published report EPA-420-R-09-020 "Light-Duty Technology Cost Analysis Pilot Study" (http://www.epa.gov/OMS/climate/420r09020.pdf).

C.4.6 <u>Packaging Database</u>

C.4.6.1 Overview

The Packaging Database contains standardized packaging options available for developing packaging costs for components and assemblies. In the cost analysis only packaging costs required to transport a component/assembly from a Tier 1 to an OEM facility (or one facility to another at the same OEM) are calculated in detail. For Tier 2/3 suppliers of high- and low-impact components, as well as purchased parts, the Tier 1 mark-up is estimated to cover the packaging as well as shipping expenses. Tier 1 mark-up on incoming Tier 2/3 parts and purchase parts are discussed in more detail in Section C.5.

All core packaging items (e.g., containers, pallets, totes) referenced in the database are considered returnable dunnage. Internal packaging (e.g., tier pads, dividers, formed trays) are also considered returnable with the exception of a few items that are expendable. The cost to clean and maintain returnable dunnage is assumed to be covered by the manufacturing overhead rate.

C.4.6.2 Types of Packaging and Selection Process

Packaging options in the database are limited to a few standard types and sizes to minimize complexity. In general, everything is tailored toward fitting onto a standard automotive pallet (as specified by the Automotive Industry Action Group), which has exterior dimensions of 48 by 45 inches and a base height assumption of 34 inches (although other standard sizes exist in 25, 33 39, 42, 48, and 50 inches in height). A standard transport trailer height of 106 inches is used as the guideline for overall packaging height.

When initially trying to package a component, three (3) typical packaging options are considered:

- standard 48 by 45 by 34-inch palletized container (with tier pads and dividers)
- 48 by 45-inch base pallet with stacked 21.5 by 15 by 12.5-inch totes (48 totes max – and note that totes can have specialized tier pads, dividers, etc.)
- 48 by 45-inch base pallet with vacuum formed dividers strapped together

Considering component attributes such as weight, size, shape, fragility, and cleanliness, one (1) of the packaging options above is selected, along with an internal dunnage scheme. If it is deemed impractical to package the component within one (1) of the primary options, a new package style is created and added to the Packaging Database.

Once the primary packaging type and associated internal dunnage are selected for a component, the assumptions along with the costs are entered into a Manufacturing Assumption Quote Summary (MAQS) worksheet. In the MAQS worksheet, packaging costs along with volume assumptions, pack densities, stock turn-over times, program life, packaging life, and interest expenses are used to calculate a cost-per-part for packaging.

C.4.6.3 Support for Costs in Packaging Database

Primary pallet and container costs are acquired from either Tier 1 automotive suppliers or from container vendors. In some cases, scaling within container groups is performed to quantify the pricing for slightly larger or smaller containers within the same family.

Internal dunnage costs are acquired from either Tier 1 automotive suppliers or calculated based on standard material and processing estimates. When tooling costs are required for packaging, the value of that tooling is added to the total pallet container piece cost, as calculated in the MAQS worksheets. The total value is then amortized to calculate a cost-per-part for packaging.

C.5 Shipping Costs

In the cost analysis, shipping costs are accounted for by one (1) of three (3) factors: (1) Indirect Cost multiplier, (2) total mark-up allowance, or (3) manufacturing overhead. Further, shipping costs are always considered freight on board (FOB) the shipper's dock, with the exception of intra-company transportation. Following are the four (4) shipping scenarios encountered in the cost analysis and how each case is handled.

In the first two (2) cases, OEM and supplier intra-company transportation, shipping costs are accounted for as part of the manufacturing overhead rate. It is assumed that the OEM or supplier would either have their own transportation equipment and/or subcontract for this service. In either case the expense is binned to manufacturing overhead.

The third case is Tier 1 shipments to an OEM facility. As stated previously the shipments are FOB the shipper's dock and thus the OEM is responsible for the shipping expense. The Indirect Cost multiplier is assumed to cover the OEM's expense to have all parts delivered to the applicable OEM manufacturing facilities.

The final case is Tier 2/3 shipments to the Tier 1 facility. Generally, the Tier 1 supplier is allowed a mark-up on incoming purchased parts from Tier 2/3 suppliers. The mark-up covers many costs including the shipping expenses to have the part delivered onto the Tier 1 supplier's dock. Further, the mark-up can either be a separate mark-up only applied to incoming purchased parts, or accounted for by the mark-up applied to the TMCs. In the former, the purchase part content would not be included in the final mark-up calculation (i.e., Mark-up = (TMC -Purchase Parts cost) x Applicable Mark-up Rate).

For this cost analysis, the latter case is chosen using the same mark-up rate for all Tier 1 value-added manufacturing as well as all incoming purchase parts.

C.6 Manufacturing Assumption and Quote Summary Worksheet

C.6.1 Overview

The Manufacturing Assumption and Quote Summary (MAQS) worksheet is the document used in the cost analysis process to compile all the known cost data, add any remaining cost parameters, and calculate a final unit cost. All key manufacturing cost information can be viewed in the MAQS worksheet for any component or assembly. Additional details on the information which flows into and out of the MAQS worksheet are discussed in more detail in following sections. Section C.8 discusses how MAQS worksheets are uploaded into subsystem, system, and vehicle summary templates to calculate the net component/assembly cost impact to the OEM.

The fundamental objective of the MAQS worksheet is similar to a standard quoting template used by the automotive industry. However, the format has been revised to capture additional quote details and manufacturing assumptions, improve on transparency by breaking out all major cost elements, and accommodate variable data inputs for the purpose of sensitivity assessments. These features are discussed in more detail in following sections.

For a given case study, all Tier 1 or OEM assemblies, identified in the CBOM as requiring cost analysis, will have a link to a MAQS worksheet. In some cases where high value final assembly Tier 2/3 parts are shipped to a Tier 1 supplier, a separate MAQS worksheet is created for greater transparency. These T2/3 MAQS worksheets are linked to T1/OEM MAQS worksheets, which in turn are referenced back to the CBOM.

Because many of the detailed spreadsheet documents generated within this analysis are too large to be shown in their entirety, electronic copies can be accessed through EPA's electronic docket ID EPA-HQ-OAR-2010-0799 (**http://www.regulations.gov)**.

C.6.2 Main Sections of Manufacturing Assumption and Quote Summary Worksheet

The MAQS worksheet, as shown in **Figure C-3** and **Figure C-4**, contains seven (7) major sections. At the top of every MAQS worksheet is an information header ***(Section A)***, which captures the basic project details along with the primary quote assumptions. The project detail section references the MAQS worksheet back to the applicable CBOM. The primary quote assumption section provides the basic information needed to put together a quote for a component/assembly. Some of the parameters in the quote assumption section are automatically referenced/linked throughout the MAQS worksheet, such as capacity planning volumes, product life span, and OEM/T1 classification. The remaining parameters in this section including facility locations, shipping methods, packing specifications, and component quote level are manually considered for certain calculations.

FEV

Technology Level:	Downsized, Turbocharged, Gasoline Direct Inject (GDI) Engine/ Compact Vehicle Class	OEM Operating Pattern (Weeks/Year):	47
Vehicle Class:	Compact/Economy 2-4 Passenger	Annual Engine Volume (CPV):	450,000
Study Case#:	N0101 (N = New, 01 = Technology Package, 01 = Vehicle Class)	Components per Engine:	4
System Description:	2007 Mini Cooper S. 1.6L I4, 16V DOHC GDI Turbo	Annual Component Volume:	1,800,000
Component Description:	Fuel Injector Assembly - Solenoid, 7 Hole	Weekly Component Volume:	38,298
Component Quote Level:	☑ Full Quote ☐ Modification Quote ☐ Differential Quote (Quote Summary includes	Estimated Product Life:	10

OEM Plant Location:	North America
Supplier Plant Location:	North America
OEM/T1 Classification:	T1 High Assembly Complexity
Shipping Method:	FOB Ship Point
Packaging Specification:	Returnable Container & Internal Dunnage

SECTION A

Part Number: 1104-N0101-01

GENERAL COMPONENT INFORMATION / GENERAL MANUFACTURING INFORMATION

Reference #	Part Description	Part Number	QTY Per Assembly	Primary Process Description	OEM/Supplier Classification	Material Specification	Labor Classification	Burden Classification
Tier 1 Supplier or OEM Processing & Assembly (Full Cost mapping)								
1A	Fuel Injector Assembly	1104-N0101-01	1	Final Assembly	T1 Assembly, Mark-up Applied @ Bottom.	Not Applicable	Electromechanical Assembly	Mech Assembly, LC, Base
2A	Seal Injector Tip	1104-N0101-01-30	1	Overmold seal @ Injector Tip	T1 Assembly, Mark-up Applied @ Bottom.	Nylon-HT, Inject.	Electromechanical Assembly	Mech Assembly, MC, Base
3A	Solenoid Body preassembled	1104-N0101-01-10	1	Insert Windings, Ring Locator a	T1 Assembly, Mark-up Applied @ Bottom.	Nylon66-40FMR, Inject.	Electromechanical Assembly	Mech Assembly, HC, Base
4A	Needle Body Assembly	1104-N0101-01-50	1	Laser weld internal valve body (	T1 Assembly, Mark-up Applied @ Bottom.	Not Applicable	Electromechanical Assembly	Mech Assembly, MC, Base
5A	Needle Assembly	1104-N0101-01-11	1	Assemble & Press Sleeve	T1 Assembly, Mark-up Applied @ Bottom.	Not Applicable	Electromechanical Assembly	Mech Assembly, MC, Base
6A	Needle Injector	1104-N0101-01-13	1	Laser Weld Ball and Seat to Needle	T1 Assembly, Mark-up Applied @ Bottom.	Not Applicable	Electromechanical Assembly	Mech Assembly, MC, Base
7A	Metering Valve assembly	1104-N0101-01-16	1	Laser Weld Plate to Valve	T1 Assembly, Mark-up Applied @ Bottom.	Not Applicable	Electromechanical Assembly	Mech Assembly, MC, Base
Purchase Part - High Impact Item (Full Cost Mapping)								
1A	Body Injector Solenoid	1104-N0101-01-20	1	Machine Body	T2/T3 CNC Turning, MSMC	S-Steel-440C, Bar	CNC Operator	CNC Turning, MC
2A	Sleeve winding to inlet separator	1104-N0101-01-27	1	Machine and Roll Splines	T2/T3 CNC Turning, MSMC	S-Steel-440C, Bar	CNC Operator	CNC Turning, MC
3A	Sleeve Fuel Inlet	1104-N0101-01-28	1	Machine	T2/T3 CNC Turning, MSMC	S-Steel-440C, Bar	CNC Operator	CNC Turning, MC
4A	Body needle	1104-N0101-01-9	1	Machine and Roll Splines	T2/T3 CNC Turning, MSMC	S-Steel-440C, Bar	CNC Operator	CNC Turning, MC
5A	Inlet Tube	1104-N0101-01-21	1	Cut and Flare	T2/T3 Hydro/CNC Form, SSLC	S-Steel-304, Tube	Forging Operator	Cold Forge, LMC
6A	Spring Seat Lower	1104-N0101-01-14	1	Machine	T2/T3 CNC Turning, MSMC	S-Steel-440C, Bar	CNC Operator	CNC Turning, MC
7A	Needle valve	1104-N0101-01-24	1	Centerless Grind	T2/T3 CNC Turning, MSMC	Not Applicable	CNC Operator	CNC Turning, MC
Purchase Part - Low Impact Item (Partial Cost Mapping = Processed Raw Material Estimate + Actual Component Assembly Process)								
Purchase Part - Commodity (Value taken from Purchase Part Database)								
1A	Solenoid Windings	1104-N0101-01-22	1		S			
2A	Ring winding locator	1104-N0101-01-26	1		S			
3A	Spring - needle to metering valve	1104-N0101-01-15	1		S			
4A	Spring Needle Return	1104-N0101-01-12	1		S			
5A	Sleeve Screen Stop	1104-N0101-01-25	1		S			
6A	Screen Fuel Inlet	1104-N0101-01-6	1		S			
7A	circlip face seal retainer	1104-N0101-01-5	1		S			
8A	Compression limiter - oring	1104-N0101-01-3	1		S			
			0					
			0					

MANUFACTURING RATES / MANUFACTURING COSTS / MARK-UP COSTS / TOTAL COSTS / TOOLING & INVESTMENT

Reference #	Finished Pieces Per Hour	Number of Operators	Number of Lines	Parallel Processing Multiplier	Material Usage "lbs"	Material Cost $/lb (DB)	Labor Rate $/Hour (DB)	Burden Rate $/Hour (DB)	Applied Burden Rate $/Hour	Material Cost	Labor/ Part	Burden/ Part	Total 1 = Material + Labor + Burden	End Item Scrap Rate (DB)	SG&A Rate (DB)	Profit Rate (DB)	ED&T/ R&D Rate (DB)	Total Mark-up Rate	Total Mark-up Cost	Total 2 = Total 1 + Total Mark-up	Total 3 = Total 2 * Qty per Ass'y	Tooling Assumptions "x1000 "	Investment Assumptions "x1000 "
Tier 1 Supplier or OEM Processing & Assembly (Full Cost mapping)																							
1A	480	2	1	6	0.000	$0.00	$37.35	$15.00	$90.00	$0.00	$0.16	$0.19	$0.34	0.00%	0.00%	0.00%	0.00%	0.00%	$0.00	$0.34	$0.34		
2A	450	1	1	1	0.005	$4.00	$37.35	$30.00	$30.00	$0.02	$0.08	$0.07	$0.17	0.00%	0.00%	0.00%	0.00%	0.00%	$0.00	$0.17	$0.17		
3A	450	2	1	5	0.030	$1.54	$37.35	$45.00	$225.00	$0.05	$0.17	$0.50	$0.71	0.00%	0.00%	0.00%	0.00%	0.00%	$0.00	$0.71	$0.71		
4A	450	4	1.5	8	0.000	$0.00	$37.35	$30.00	$360.00	$0.00	$0.33	$0.80	$1.13	0.00%	0.00%	0.00%	0.00%	0.00%	$0.00	$1.13	$1.13		
5A	450	1	1	4	0.000	$0.00	$37.35	$30.00	$120.00	$0.00	$0.08	$0.27	$0.35	0.00%	0.00%	0.00%	0.00%	0.00%	$0.00	$0.35	$0.35		
6A	514	1	1	3	0.000	$0.00	$37.35	$30.00	$90.00	$0.00	$0.07	$0.18	$0.25	0.00%	0.00%	0.00%	0.00%	0.00%	$0.00	$0.25	$0.25		
7A	514	1	1	2	0.000	$0.00	$37.35	$30.00	$60.00	$0.00	$0.07	$0.12	$0.19	0.00%	0.00%	0.00%	0.00%	0.00%	$0.00	$0.19	$0.19		
Purchase Part - High Impact Item (Full Cost Mapping)																							
1A	500	0.5	5	1	0.140	$4.56	$35.70	$45.00	$225.00	$0.64	$0.04	$0.45	$1.12	0.50%	6.50%	6.00%	1.00%	14.00%	$0.16	$1.28	$1.28		
2A	491	0.5	4.5	1	0.074	$4.56	$35.70	$45.00	$202.50	$0.34	$0.04	$0.41	$0.79	0.50%	6.50%	6.00%	1.00%	14.00%	$0.11	$0.90	$0.90		
3A	485	0.5	3.5	1	0.041	$4.56	$35.70	$45.00	$157.50	$0.19	$0.04	$0.33	$0.55	0.50%	6.50%	6.00%	1.00%	14.00%	$0.08	$0.63	$0.63		
4A	460	0.5	5.5	1	0.043	$4.56	$35.70	$45.00	$247.50	$0.20	$0.04	$0.54	$0.77	0.50%	6.50%	6.00%	1.00%	14.00%	$0.11	$0.88	$0.88		
5A	360	0.5	1	1	0.010	$1.65	$38.52	$100.09	$100.09	$0.02	$0.05	$0.28	$0.35	0.30%	6.00%	4.00%	0.00%	10.30%	$0.04	$0.38	$0.38		
6A	450	0.25	1.5	1	0.0002	$4.56	$35.70	$45.00	$67.50	$0.00	$0.02	$0.15	$0.17	0.50%	6.50%	6.00%	1.00%	14.00%	$0.02	$0.19	$0.19		
7A	540	0.25	1.5	1	0.000	$0.00	$35.70	$45.00	$67.50	$0.00	$0.02	$0.13	$0.14	0.50%	6.50%	6.00%	1.00%	14.00%	$0.02	$0.16	$0.16		
Purchase Part - Low Impact Item																							
Purchase Part - Commodity																		Supplier Account Cost	Purchase Price/ Unit	Purchase Price Net, PIA	Purchase Price Net, End Item		
1A																		$0.00	$0.25	$0.00	$0.25		
2A																		$0.00	$0.08	$0.00	$0.08		
3A																		$0.00	$0.01	$0.00	$0.01		
4A																		$0.00	$0.03	$0.00	$0.03		
5A																		$0.00	$0.01	$0.00	$0.01		
6A																		$0.00	$0.05	$0.00	$0.05		
7A																		$0.00	$0.02	$0.00	$0.02		
8A																		$0.00	$0.03	$0.00	$0.03		
																		$0.00	$0.00	$0.00	$0.00		
																		$0.00	$0.00	$0.00	$0.00		

SECTION B

"S"=Indicates Component is Supplied directly to T1 or OEM for Final or Sub-Assembly.

"SAC"=(Supplier Accounted Costs) Indicates Component is Supplied directly to T1 or OEM for Final or Sub-Assembly. In addition component material cost is accounted for in T1 quote sheet. Thus component cost will only be included for Mark-up Calculations.

"Alpha-Numeric Character" = Indicates purchase parts are brought in by T2/T3 Supplier for Subassembly.

[redacted]

Figure C-3: Sample MAQS Costing Worksheet (Part 1 of 2)

Costs Broken Out Into Categories with Quantity per Assembly Taken into Account								
Manufacturing Cost				Mark-up Cost				
Material	Labor	Burden	Total Mfg'ing Cost (Component/ Assembly)	End Item Scrap	SG&A	Profit	ED&T-R&D	Total Markup Cost (Component/ Assembly)
$0.00	$0.16	$0.19	$0.34	$0.00	$0.00	$0.00	$0.00	$0.00
$0.02	$0.08	$0.07	$0.17	$0.00	$0.00	$0.00	$0.00	$0.00
$0.05	$0.17	$0.50	$0.71	$0.00	$0.00	$0.00	$0.00	$0.00
$0.00	$0.33	$0.80	$1.13	$0.00	$0.00	$0.00	$0.00	$0.00
$0.00	$0.08	$0.27	$0.35	$0.00	$0.00	$0.00	$0.00	$0.00
$0.00	$0.07	$0.18	$0.25	$0.00	$0.00	$0.00	$0.00	$0.00
$0.00	$0.07	$0.12	$0.19	$0.00	$0.00	$0.00	$0.00	$0.00
$0.64	$0.04	$0.45	$1.12	$0.01	$0.07	$0.07	$0.01	$0.16
$0.34	$0.04	$0.41	$0.79	$0.00	$0.05	$0.05	$0.01	$0.11
$0.19	$0.04	$0.33	$0.55	$0.00	[illegible]	$0.03	$0.01	$0.08
$0.20	$0.04	$0.54	$0.77	$0.00	$0.05	[illegible]	$0.01	$0.11
$0.02	$0.05	$0.28	$0.35	$0.00	$0.02	$0.01	$0.00	$0.04
$0.00	$0.02	$0.15	$0.17	$0.00	$0.01	$0.01	$0.00	$0.02
$0.00	$0.02	$0.13	$0.14	$0.00	$0.01	$0.01	$0.00	$0.02
$0.25			$0.25					
$0.08			$0.08					
$0.01			$0.01					
$0.03			$0.03					
$0.01			$0.01					
$0.05			$0.05					
$0.02			$0.02					
$0.03			$0.03					
$0.00			$0.00					
$0.00			$0.00					
Material	Labor	Burden	TMC	Scrape	SG&A	Profit	ED&T	Mark-up Total
$2.16	$1.47	$6.44	$10.07	$0.03	$0.41	$0.38	$0.06	$0.89
							2	$10.95

SECTION C

Notes:
a) Items 1,2, & 3 must all equal same value otherwise there is a computation error.

MANUFACTURING ASSUMPTIONS																				
Process Information	Projected Operating Pattern						Minimum Calculated Cycles Time					Project Process Requirement								
Process & Equipment Assumptions	Days/ Week	Shifts./ Day	Hrs./ Shift	Hrs./ Wk	Wks./ Yr.	Hrs./ Yr.	Pcs./ Hr. (100% Eff.)	Cycle Time/Operation "Sec."	Efficiency %	Pcs./ Hr. @ Stated Efficiency	Cycle Time/Operation @ Stated Efficiency "Sec."	Lean Design Calculation for Complete Process Time "Sec."	Parallel Operations/Machine or Stations/Line	Piece/Cycle/Machine	Tack Time/Machine/Cycle "Seconds"	Multiplier, If Required for Parallel Processing (1=Nothing)	Number of Equivalent Machines Required	Resulting Pieces/Hour	Resulting Cycle Time/ Part "Sec.	Total Number of Direct Operators
Semi Automated Line with Operator load and unload. St#1, Operator load injector assembly w. face seal., St#2, install circlip face seal, S#3Press Screen Stop and filter, S#4 Install Compression Limiter Oring and Oring Injector, S#5, Install Bracket Hold Down, S# 6Test & Label, #7 Operator Unload & Pack	5	2	10	100	47	4700	383	9.40	85%	451	7.99	-	7	2	15	6.0	1.0	480	7.50	2.00
Operator Load and Unload, Single Station, tip seal install and size.	5	2	10	100	47	4700	383	9.40	85%	451	7.99	-	1	2	16	1.0	1.0	450	8.00	1.00
Linear Transfer line feeding 2 Vertical Injection Press. Both 4 Cavities (2x2). Linear Transfer Line, St#1 Press Needle Body Assembly into Solenoid Body, St#2, Insert Coil and Ring Locator and Press Home, St#3 Load into Mold, ST# 4 Overmold., ST#5 Transfer to secondary overmold.	5	2	10	100	47	4700	383	9.40	85%	451	7.99	-	5	2	16	5.0	1.0	450	8.00	2.00
Automated Rotary Laser weld table with operator load assist and unload. S# 1 & 2 load pallet, S# 3 Fixture & Weld, S5 Fixture&Weld, S#6 Cool, S#7 Re-orientate, S#8 Insert Valve Assembly/Spring and Sleeve, S#9 Install Inlet Tube, S#10 laser Weld, S#11 Cool, Station 12 Test and Pack.	5	2	10	100	47	4700	383	9.40	85%	451	7.99	-	12	1	12	8.0	1.5	450	8.00	4.00
Semi automated load to pallet, automatic fixture and press. Operator assistance on load and unload.	5	2	10	100	47	4700	383	9.40	85%	451	7.99	32	4	1	8	4.0	1.0	450	8.00	1.00
Automated component feed and laser weld assembly station (load, fixture & clamp, weld#1, weld#2, unload)	5	2	10	100	47	4700	383	9.40	85%	451	7.99	21	3	1	7	3.0	1.0	514	7.00	1.00
Automated component feed and laser weld assembly station (load, fixture&clamp, weld, unload)	5	2	10	100	47	4700	383	9.40	85%	451	7.99	13	2	1	7.0	2.0	1.0	514	7.00	1.00
Multi Spindle CNC Turning Machine + Batch Wash	5	2	10	100	47	4700	383	9.40	85%	451	7.99	46	1	1	36	1.0	5.0	500	7.20	0.50
Multi Spindle CNC Turning Machine + Batch Wash	5	2	10	100	47	4700	383	9.40	85%	451	7.99	43	1	1	33	1.0	4.5	491	7.33	0.50
Multi Spindle CNC Turning Machine + Batch Wash	5	2	10	100	47	4700	383	9.40	85%	451	7.99	36	1	1	26	1.0	3.5	485	7.43	0.50
Multi Spindle CNC Turning Machine + Batch Wash	5	2	10	100	47	4700	383	9.40	85%	451	7.99	53	1	1	43	1.0	5.5	460	7.82	0.50
Cold Form Press with automated part handling	5	2	10	100	47	4700	383	9.40	85%	451	7.99	33	4	1	10	1.0	1.0	360	10.00	0.50
Automated CNC, Feed and Machine, Batch Wash	5	2	10	100	47	4700	383	9.40	85%	451	7.99	-	1	1	12	1.0	1.5	450	8.00	0.25
Hopper feed to centerless grinding	5	2	10	100	47	4700	383	9.40	85%	451	7.99	-	3	1	10	1.0	1.5	540	6.67	0.25

SECTION D

PACKAGING CALCULATIONS:
Packaging Type: Option #0 Tote, 42 Totes/Pallet
Part Size: 90x55x25 mm
Parts/Layer per tote: 3 x 8
Number of Layers per tote: 9

	Cost per Piece		Total Amount	Lump Sum Payment (X)	Total # of Pieces/ Amortization Period	Number of Service Months	Interest Rate		Cost per Pallet /Rack	Total Number of Pallets/ Racks Required	Number of Parts per Pallet/ Rack	Supplier, Customer and In-transit Inventory	Supplier, Customer and In-transit Inventory
Rack/Pallet Investment Amortization:	$0.014		$108,680	0.00%	9,000,000	60	1.00%		$4,180	26	9072	6	229707
	Cost per Piece		Tier Pad Price Per	Tier Pads Pallet/Rack	Divider Pads, Price Per	Divider Pads Pallet/Rack	Other #1 Packaging Price Per	Other #1 Pads Pallet/ Rack	Other #2 Packaging Price Per	Other #2 Pads Pallet/ Rack	Other #3 Packaging Price Per	Other #3 Pads Pallet/ Rack	
Expendable Packaging in Piece Cost:	$0.00		$0.00	0	$0.00	0	$0.00	0	$0.00	0	$0.00	0	
Packaging Cost Total:	$0.014												

SECTION E

Figure C-4: Sample MAQS Costing Worksheet (Part 2 of 2)

Two (2) parameters above whose functions perhaps are not so evident from their names are the "OEM/T1 classification" and "component quote level."

The "OEM/T1 classification" parameter addresses who is taking the lead on manufacturing the end-item component, the OEM or Tier 1 supplier. Also captured is the OEM or Tier 1 level, as defined by size, complexity, and expertise level. The value entered into the cell is linked to the Mark-up Database, which will up-load the corresponding mark-up values from the database into the MAQS worksheet. For example, if "T1 High Assembly Complexity" is entered in the input cell, the following values for mark-up are pulled into the worksheet: Scrap = 0.70%, SG&A = 7%, Profit = 8.0% and ED&T = 4%. These rates are then multiplied by the TMC at the bottom of the MAQS worksheet to calculate the applied mark-up as shown in **Figure C-5**.

The process for selecting the classification of the lead manufacturing site (OEM or T1) and corresponding complexity (e.g., High Assembly Complexity, Moderate Assembly Complexity, Low Assembly Complexity) is based on the team's knowledge of existing value chains for same or similar type components.

OEM Operating Pattern (Weeks/Year):	47	OEM Plant Location:	North America
Annual Engine Volume (CPV):	450,000	~~Supplier Plant Location:~~	~~North America~~
Components per Engine:	4	OEM/T1 Classification:	T1 High Assembly Complexity
Annual Component Volume:	1,800,000	Shipping Method:	FOB Ship Point
Weekly Component Volume:	38,298	Packaging Specification:	Returnable Container & Internal Dunnage
Estimated Product Life:	10		

TMC

	Material	Labor	Burden	TMC	Scrap	SG&A	Profit	ED&T	Total Mark-up		$10.95
T1 or OEM Total Manufacturing Cost:	$2.16	$1.47	$6.44	$10.07	$0.03	$0.41	$0.38	$0.06	$0.89		$10.95
T1 or OEM Mark-Up Rates:	-----	-----	-----	-----	0.70%	7.00%	8.00%	4.00%	19.70%		
(SAC) &T1 or OEM Mark-Up Values:	0.00	-----	-----	-----	$0.08	$0.77	$0.88	$0.44	$2.16		
Base Cost Impact to Vehicle:	$2.16	$1.47	$6.44	$10.07	$0.11	$1.18	$1.26	$0.50	$3.05		$13.11
										Packaging Cost:	$0.01
										Net Cost Impact to Vehicle:	$13.13

Figure C-5: Excerpt Illustrating Automated Link between OEM/T1 Classification Input in MAQS Worksheet and the Corresponding Mark-up Percentages Uploaded from the Mark-up Database

The "component quote level" identifies what level of detail is captured in the MAQS worksheet for a particular component/assembly, full quote, modification quote, or differential quote. When the "full quote" box is checked, it indicates all manufacturing costs are captured for the component/assembly. When the "modification quote" box is checked, it indicates only the changed portion of the component/assembly has been quoted. A differential quote is similar to a modification quote with the exception that information from both technology configurations, is brought into the same MAQS worksheet, and a differential analysis is conducted on the input cost attributes versus the output cost attributes. For example, if two (2) brake boosters (e.g., HEV booster and baseline vehicle booster) are being compared for cost, each brake booster can have its differences quoted in a separate MAQS worksheet (modification quote) and the total cost outputs for each can be subtracted to acquire the differential cost. Alternatively in a single MAQS worksheet the cost driving attributes for the differences between the booster's (e.g., mass difference on common components, purchase component differences, etc.) can be offset, and the differential cost calculated in a single worksheet. The differential quote method is typically employed those components with low differential cost impact to help minimize the number of MAQS worksheets generated.

From left to right, the MAQS worksheet is broken into two (2) main sections as the name suggests, a quote summary ***(Section B)*** and manufacturing assumption section ***(Section D).*** The manufacturing assumption section, positioned to the right of the quote summary section, is where the additional assumptions and calculations are made to convert the serial processing operations from Lean Design® into mass production operations. Calculations made in this section are automatically loaded into the quote summary section. The quote summary section utilizes this data along with other costing database data to calculate the total cost for each defined operation in the MAQS worksheet.

Note "defined operations" are all the value-added operations required to make a component or assembly. For example, a high pressure fuel injector may have twenty (20) base level components which all need to be assembled together. To manufacture one (1) of the base level components there may be as many as two (2) or three (3) value-added process operations (e.g., cast, heat treat, machine). In the MAQS worksheet each of these process operations has an individual line summarizing the manufacturing assumptions and costs for the defined operation. For a case with two (2) defined operations per base level component, plus two (2) subassembly and final assembly operations, there could be as many as forty (40) defined operations detailed out in the MAQS worksheet. For ease of viewing all the costs associated with a part, with multiple value-added operations, the operations are grouped together in the MAQS worksheet.

Commodity based purchased parts are also included as a separate line code in the MAQS worksheet. Although there are no supporting manufacturing assumptions and/or calculations required since the costs are provided as total costs.

From top to bottom, the MAQS worksheet is divided into four (4) quoting levels in which both the value-added operations and commodity-based purchase parts are grouped: (1) Tier 1 Supplier or OEM Processing and Assembly, (2) Purchase Part – High Impact Items, (3) Purchase Part – Low Impact Items, and (4) Purchase Part – Commodity. Each quoting level has different rules relative to what cost elements are applicable, how cost elements are binned, and how they are calculated.

Items listed in the ***Tier 1 Supplier or OEM Processing and Assembly*** section are all the assembly and subassembly manufacturing operations assumed to be performed at the main OEM or T1 manufacturing facility. Included in manufacturing operations would be any on-line attribute and/or variable product engineering characteristic checks. For this quote level, full and detailed cost analysis is performed (with the exception of mark-up which is applied to the TMC at the bottom of the worksheet).

Purchase Part – High Impact Items include all the operations assumed to be performed at Tier 2/3 (T2/3) supplier facilities and/or T1 internal supporting facilities. For this quote level detailed cost analysis is performed, including mark-up calculations for those components/operations considered to be supplied by T2/3 facilities. T1 internal supporting facilities included in this category do not include mark-up calculations. As mentioned above, the T1 mark-up (for main and supporting facilities) is applied to the TMC at the bottom of the worksheet.

Purchase Part – Low Impact Items are for *higher priced* commodity based items which need to have their manufacturing cost elements broken out and presented in the MAQS sheet similar to high impact purchase parts. If not, the material cost group in the MAQS worksheet may become distorted since commodity based purchase part costs are binned to material costs as discussed previously in Section C.4.2.5 Purchase Parts – Commodity Parts. ***Purchase Part – Commodity Parts*** are represented in the MAQS worksheet as a single cost and are binned to material costs.

At the bottom of the MAQS worksheet ***(Section F)***, all the value-added operations and commodity-based purchase part costs, recorded in the four (4) quote levels, are automatically added together to obtain the TMC. The applicable mark-up rates based on the T1 or OEM classification recorded in the MAQS header are then multiplied by the TMC to obtain the mark-up contribution. Adding the TMC and mark-up contribution together, a subtotal unit cost is calculated.

Important to note is that throughout the MAQS worksheet, all seven (7) cost element categories (material, labor, burden, scrap, SG&A, profit, and ED&T) are maintained in the analysis. ***Section C***, MAQS breakout calculator, which resides between the quote summary and manufacturing assumption sections, exists primarily for this function.

The last major section of the MAQS worksheet is the packaging calculation, ***Section E***. In this section of the MAQS worksheet a packaging cost contribution is calculated for each part based on considerations such as packaging requirements, pack densities, volume assumptions, stock, and/or transit lead times.

The sample packaging calculation (**Figure C-6**) is taken from the high voltage traction battery subsystem (140301 Battery Module MAQS worksheet, Case Study #N0502). In this example, a minimum of two (2) weeks of packaging are required to support inventory and transit lead times. This equates to packaging for 19,149 parts over the two (2) weeks, based off the weekly capacity planning rates. There are 15 pieces per pallet at a packaging hardware cost of $575 per pallet (container and internal dunnage costs are from the Packaging Database). From this information, 1,277 pallet sets are required at $575/set, totaling $734,275 in packaging costs. Packaging is estimated to last thirty-six (36) months. Thus applying the amortization formula based on thirty-six (36) months, 5% interest, and 1.35 million parts/36 months yields $0.585/part. This cost is added to the subtotal unit cost (TMC + mark-up) to obtain the Total Unit Cost.

Note that in this case both the container and dunnage are assumed returnable. Thus, the bottom section of the packaging calculator is not used.

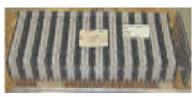
PACKAGING CALCULATIONS: Packaging Type: Option#2 Part Size: 1000x 300 x 140 Parts/Layer: 3 Number of Layers: 5 	Packaging Cost per Piece	Total Amount	Lump Sum Payment (%)	Total # of Pieces	Number of Months	Interest Rate		Cost per Pallet /Rack	Total Number of Pallets/ Racks Required	Number of Parts per Pallet/ Rack	Supplier, Customer and In-transit Inventory Requirements (Weeks)	Supplier, Customer and In-transit Inventory Requirements (Parts)
Rack/Pallet Investment Amortization:	$0.585	$734,275	0.00%	1,350,000	36	5.00%		$575	1277	15	2	19149
	Packaging Cost per Piece	Tier Pad Price Per	Tier Pads Pallet/Rack	Divider Pads, Price Per	Divider Pads Pallet/Rack	Other #1 Packaging Price Per	Other #1 Pads Pallet/Rack	Other #2 Packaging Price Per	Other #2 Pads Pallet/Rack	Other #3 Packaging, Price Per	Other #3 Pads Pallet/Rack	
Expendable Packaging in Piece Cost:	$0.00	$0.00	0	$0.00	0	$0.00	0	$0.00	0	$0.00	0	
Packaging Cost Total:	$0.585											

Figure C-6: Example of Packaging Cost Calculation for Base Battery Module

C.7 Marketplace Validation

Marketplace validation is the process by which individual parts, components, and/or assemblies are cross-checked with costing data developed by entities and processes external to the team responsible for the cost analysis. This process occurs at all stages of the cost analysis, with special emphasis is placed on cross-checking in-process costs (e.g., material costs, material selection, labor costs, manufacturing overhead costs, scrap rates, and individual component costs within an assembly).

In-process cost validation occurs when a preliminary cost has been developed for a particular part within an assembly, and the cost is significantly higher or lower than expected based on the team's technical knowledge or on pricing from similar components. In this circumstance, the cost analysis team would first revisit the costs, drawing in part/process-specific internal expertise and checking surrogate parts from previously costed bills of materials where available. If the discrepancy is still unresolved, the team would rely on automotive supplier networks, industry experts, and/or publicly available publications to validate the cost assumptions, making changes where warranted.

Cross-checking on final assembly costs also occurs within the scope of the cost analysis, mainly as a "big picture" check. Final assembly costs, in general cross-checking, are typically achieved through solicitation of industry experts. The depth of cross-checking ranges from simple comparison of cost data on surrogate assemblies to full Manufacturing Assumption and Quote Summary (MAQS) worksheet reviews.

C.8 Cost Model Analysis Templates

C.8.1 Subsystem, System and Vehicle Cost Model Analysis Templates

The Cost Model Analysis Templates (CMAT) are the documents used to display and roll-up all the costs associated with a particular subsystem, system or vehicle. At the lowest level of the hierarchy, the manufacturing assumption quote summary worksheets, associated with a particular vehicle subsystem, are directly linked to the subsystem CMAT. All the subsystems cost breakdowns, associated with a particular system, are directly linked to the relevant system CMAT. Similarly, all the system cost breakdown summaries are directly linked to the vehicle CMAT. The top-down layering of the incremental costs, at the various CMAT levels, paints a clear picture of the cost drivers at all levels for the adaptation of the advance technology. In addition, since all databases, MAQS worksheets, and CMATs are linked together, the ability to understand the impact of various cost elements on the incremental cost can be readily understood.

D. 2010 Ford Fusion Power-Split HEV Cost Analysis, Case Study #0502

D.1 Vehicle & Cost Summary Overview

D.1.1 Vehicle Comparison Overview

For this case study, two (2) Ford Motor Company vehicles were chosen that utilize the same vehicle platform and were produced on the same assembly line (Hermosillo, Mexico). The differences between the 2010 Fusion SE and 2010 Fusion Hybrid are the subject matter of this study. These vehicles provided a very effective means of analyzing the cost impact when advanced propulsion technology is integrated throughout a vehicle platform.

Figure D-1: 2010 Fusion SE (Left) and 2010 Fusion Hybrid (Right)

Both vehicles are comparably equipped four door sedans. The Fusion SE has a conventional front-wheel drive layout with a 3.0 liter V6 internal combustion engine (ICE) coupled to a 6-speed automatic transaxle.

The Fusion Hybrid's powertrain retained a front-wheel drive layout, but coupled a 2.5 liter inline 4 cylinder Atkinson ICE with an electronic continuous variable transmission (eCVT). The eCVT module contains both an electric traction motor and generator coupled to the ICE through a single planetary gear set. The Motor Control Unit (MCU), Generator Control Unit (GCU), and Transmission Control Unit (TCU), as well as other required high-power electronic components, are all contained within the eCVT. To keep the primary components (e.g. power electronics, control electronics, motors/generator, gearing) of the eCVT within an acceptable operating temperature, a separate cooling circuit consisting primarily of an electrically operated coolant pump and heat exchanger were added to the HEV vehicle over the baseline.

The high voltage power supply for the electric motor and generator consists of a 275V, 5.5 Ampere-Hour (Ah) nickel metal hydride (NiMH) traction battery and dedicated HV electrical harness. The battery module is positioned between the C-pillars of the vehicle directly behind the rear passenger seat. To keep the battery temperature within a safe and functional operating temperature, a forced air cooling system was integrated into the battery module. Modifications to the rear seat were required to support the flow of cooler air from the passenger cabin through the battery module, exhausting the heated air into the rear truck compartment.

The Fusion HEV retained a 12-volt system to operate all non-hybrid vehicle systems. However a DC-DC converter replaced the alternator for charging the 12-volt battery.

In addition to the primary system changes (e.g., engine, transmission, power supply and power distribution) required for the adaptation of power-split HEV technology, changes to less "technology critical" systems were also made: Such as the change over from a mechanical driven AC compressor to an electrical-driven compressor and the addition of an auxiliary electric-coolant pump. Both are examples of climate control system components requiring modifications to accommodate ICE shutdown.

As a further means to try and improve the percent of regenerative brake capture, Ford also elected to launch their new power-split HEV technology with a brake-by-wire system. The adaptation of brake-by-wire technology over the conventional braking system resulted in a series of changes to brake actuation, power brake, and brake controls subsystems.

These various vehicle systems discussed, which were modified either as a direct or indirect result of the adaptation of HEV power-split technology, were all included in the analysis since all had some level of cost impact over the baseline vehicle. It should be noted that component differences existed in other systems (e.g., suspension, frame and mounting, driveline, electrical feature) between the Fusion SE (baseline) and Fusion Hybrid (power-split HEV). Many of these differences were related to component placement, component tuning, or feature addition differences between the two vehicles. Upon team review, many of the differences were determined to be insignificant from a cost perspective, as the component differences were estimated to have minor impact, there were offsetting component costs within the systems, or the component/technology addition was not a mandatory requirement driven by the adaptation of power-split HEV technology.

An illustration of the HEV power-split basic concept can be found in Section A, **Figure A-1**.

A vehicle specification summary, fuel economy and emissions summary, and performance summary of the 2010 Ford Fusion SE (representing baseline technology configuration) and 2010 Ford Fusion Hybrid (representing power-split HEV technology configuration) are shown in **Table D-1**, **Table D-2**, and **Table D-3**, respectively.

Figure D-2 illustrates mass distribution for both the Ford Fusion HEV and Fusion SE vehicles. The net vehicle mass difference, as measured, was approximately 240lbs. As shown in the figure, the increase in mass, attributed to power-split component addition/modification, had a very minor effect on left side/right side and front/rear weight distribution as measured.

Table D-1: Vehicle Specification Summary

Model	2010 Fusion SE	2010 Fusion Hybrid
Curb Weight	3446 lbs.	3720 lbs.
Drive Layout	Front Wheel Drive	Front Wheel Drive
Engine Mounting	Front Engine, Transverse Mount	Front Engine, Transverse Mount
Tire Size	225 / 50 R17 93V	225 / 50 R17 93V
Engine	3.0L-V6	2.5L-I4
Emission Certification	Tier 2 Bin 4 / LEV-II ULEV	Tier 2 Bin 3 / LEV-II SULEV
Fuel Tank Capacity	66.2L (17.5 US gal.)	66.2L (17.5 US gal.)
Transmission	6-Speed Automatic (6F35)	eCVT
Coefficient of Drag (Cd)	0.32	0.32

(*Source of information contained in this table is Ford Motor Company sales/service literature except Cd, which was collected from various online sources, all in agreement.*)

Table D-2: Fuel Economy and Emissions Summary

Model	2010 Fusion SE	2010 Fusion Hybrid
EPA City Fuel Economy (87 octane/ E85)	18 / 13	41
EPA Highway Fuel Economy (87 octane / E85)	27 / 19	36
EPA Combined (87 octane / E85)	21 / 15	39
Estimated Range (87 octane / E85)	367 / 262	663
Emission Certification	Tier 2, Bin 4 / LEV-II ULEV	Tier 2, Bin 3 / LEV-II SULEV
Engine Family	AFMXV03.0VDF	AFMXV02.5VZH
EVAP Family	AFMXR0155GAV	AFMXR0120GCX

(Source of information contained in this table is Ford Motor Company Monroney stickers and emissions placards)

Table D-3: Performance Summary

Model	2010 Fusion SE	2010 Fusion Hybrid
Engine Horsepower	240 hp (179 kW) @ 6,550 rpm	156 hp (116 kW) @6,5000 rpm
Electric Motor Horsepower	N/A	106 hp (79 kW) @ 6,500 rpm
Net Horsepower	N/A	191 hp (142 kW) @ 6,000 rpm
Engine Torque	223 ft-lb (302 Nm) @ 4,300 rpm	136 ft-lb (184 Nm) @ 2,250 rpm
Electric Motor Torque	N/A	166 ft-lb (225 Nm) @ 3,000 rpm
0-60 mph / ¼ mile	7.3 sec. / 15.3 sec. @ 91.8 mph*	8.7 sec. / 16.4 sec. @ 87.8 mph**
Power to Weight Ratio	19.5 lb. / hp	14.4 lb. / hp
Specific Output	62.4 HP / Liter	80.0 HP / Liter
Redline	6,600 rpm	6,550 rpm

*(Source of information contained in this table is Ford Motor Company sales/service literature except 0-60 mph / ¼ mile data: *Source edmunds.com, **Source Edmunds InsideLine)*

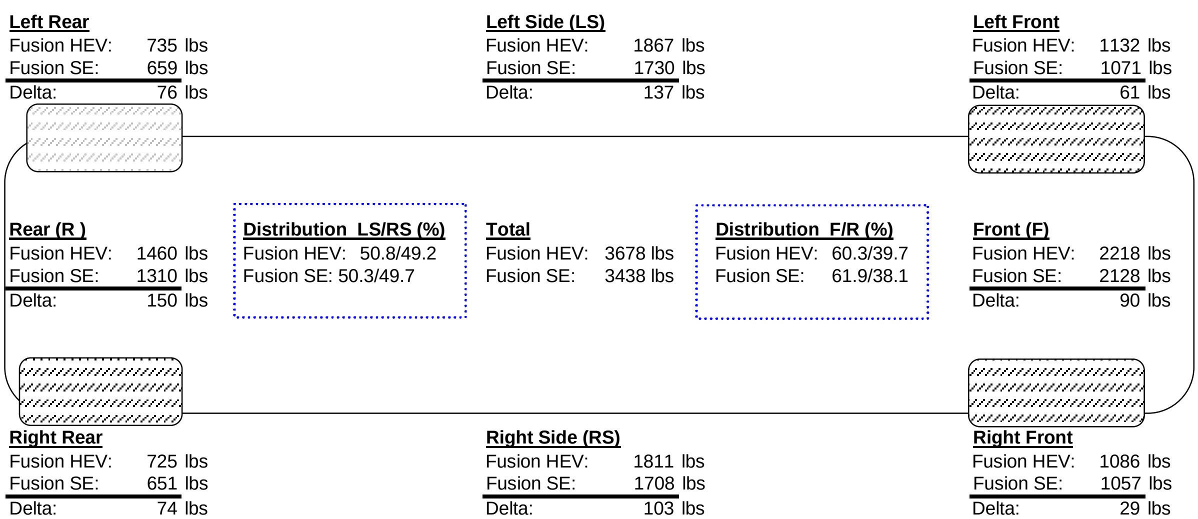


Figure D-2: Fusion HEV and Fusion Base Vehicle Mass Distributions as Measured

(Vehicles weighed with 6 gallons of fuel in each tank)

D.1.2 Direct Manufacturing Cost Difference for a 2010 Ford Fusion Power-Split HEV compared to a 2010 Ford Fusion SE Baseline Vehicle

A summary of the calculated, net incremental, direct manufacturing costs for producing a Ford Fusion Hybrid vehicle over the baseline Ford Fusion SE is presented in **Table D-4**. The costs, captured only for vehicle differences having an overall positive or negative cost impact, are broken out for each of the major systems in both the Fusion HEV (New Technology Configuration) and Fusion SE (Baseline Technology Configuration). At the bottom of the table, the baseline configuration costs are subtracted from the new technology configuration costs resulting in a net incremental cost

From the cost element breakdown within the table, approximately 71% of the incremental direct manufacturing costs (i.e., $2,865.06) are material costs, 14% labor costs, and 15% overhead costs. Relative to the net incremental direct manufacturing cost of $3,435, approximately 83.5% are total manufacturing costs (i.e., material, labor, overhead) and the remaining 16.5% is applicable mark-up.

More than 95% of the costs for adding the power-split technology to the baseline configuration originate from the transmission (34%) and electrical power supply (63%) systems.

In the sections which follow, additional details on the components evaluated within each vehicle system and their associated costs will be discussed.

Table D-4: Net Incremental Direct Manufacturing Cost of Ford Fusion HEV Over Ford Fusion SE

SYSTEM & SUBSYSTEM DESCRIPTION — **NEW TECHNOLOGY GENERAL PART INFORMATION: 2010 Ford Fusion HEV, 2.5L Atkinson Cycle, I4, 156hp (191 Net), (NiMH Battery 275V, Nominal Pack Capacity 5.5Ah, 1.51kWh)**

Item	System Description	Manufacturing: Material	Manufacturing: Labor	Manufacturing: Burden	Total Manufacturing Cost (Component/ Assembly)	Markup: End Item Scrap	Markup: SG&A	Markup: Profit	Markup: ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
	000000 Vehicle											
1	01 Engine System	$ 506.26	$ 145.72	$ 518.82	$ 1,170.80	$ 17.66	$ 55.10	$ 54.28	$ 19.29	$ 146.33	$ 3.80	$ 1,320.94
2	02 Transmission System	$ 1,010.34	$ 331.85	$ 532.55	$ 1,874.73	$ 17.46	$ 127.56	$ 132.73	$ 57.79	$ 335.54	$ 6.16	$ 2,216.43
3	03 Body System	$ 32.76	$ 18.10	$ 13.06	$ 63.92	$ 0.59	$ 7.64	$ 7.11	$ 2.27	$ 17.62	$ 0.17	$ 81.71
4	06 Brake System	$ 113.54	$ 51.26	$ 67.54	$ 232.34	$ 1.88	$ 20.60	$ 17.75	$ 5.98	$ 46.21	$ 0.51	$ 279.06
5	09 Exhaust System (Included In Engine Downsizing Credit)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
6	12 Climate System	$ 176.13	$ 29.38	$ 48.59	$ 254.11	$ 2.12	$ 17.46	$ 16.48	$ 6.89	$ 42.95	$ 0.15	$ 297.21
7	14 Electrical Power Supply System	$ 1,383.60	$ 191.52	$ 315.70	$ 1,890.81	$ 14.22	$ 127.76	$ 136.21	$ 64.40	$ 342.59	$ 3.56	$ 2,236.96
8	18 Electrical Distribution and Control System	$ 127.00	$ 32.43	$ 16.16	$ 175.58	$ 0.81	$ 10.64	$ 9.75	$ 4.03	$ 25.23	$ 0.68	$ 201.50
	VEHICLE ROLL-UP	$ 3,349.62	$ 800.27	$ 1,512.41	$ 5,662.30	$ 54.75	$ 366.75	$ 374.32	$ 160.66	$ 956.47	$ 15.04	$ 6,633.81

SYSTEM & SUBSYSTEM DESCRIPTION — **BASE TECHNOLOGY GENERAL PART INFORMATION: 2010 Ford Fusion SE, 3.0L V6, 4-Val. DOHC, NA, PFI, 240hp, 223lb*ft**

Item	System Description	Manufacturing: Material	Manufacturing: Labor	Manufacturing: Burden	Total Manufacturing Cost (Component/ Assembly)	Markup: End Item Scrap	Markup: SG&A	Markup: Profit	Markup: ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
	000000 Vehicle											
1	01 Engine System	$ 715.90	$ 206.07	$ 733.66	$ 1,655.63	$ 24.98	$ 77.91	$ 76.76	$ 27.28	$ 206.93	$ 5.38	$ 1,867.94
2	02 Transmission System	$ 492.10	$ 140.17	$ 274.33	$ 906.60	$ 6.51	$ 59.17	$ 55.27	$ 15.12	$ 136.07	$ 4.49	$ 1,047.17
3	03 Body System	$ 24.88	$ 18.04	$ 14.89	$ 57.81	$ 0.60	$ 7.67	$ 7.13	$ 2.19	$ 17.59	$ -	$ 75.39
4	06 Brake System	$ 14.08	$ 9.91	$ 12.51	$ 36.50	$ 0.18	$ 2.45	$ 2.27	$ 0.87	$ 5.76	$ 0.12	$ 42.39
5	09 Exhaust System (Included In Engine Downsizing Credit)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
6	12 Climate System	$ 24.10	$ 19.18	$ 25.92	$ 69.20	$ 0.58	$ 6.52	$ 5.56	$ 1.89	$ 14.56	$ -	$ 83.75
7	14 Electrical Power Supply System	$ 32.50	$ 11.05	$ 27.95	$ 71.50	$ 0.34	$ 4.42	$ 4.08	$ 1.70	$ 10.54	$ 0.13	$ 82.17
8	18 Electrical Distribution and Control System	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	VEHICLE ROLL-UP	$ 1,303.57	$ 404.42	$ 1,089.25	$ 2,797.24	$ 33.19	$ 158.14	$ 151.07	$ 49.05	$ 391.45	$ 10.11	$ 3,198.80

SYSTEM & SUBSYSTEM DESCRIPTION — **NET DIRECT INCREMENTAL MANUFACTURING COST TO UPGRADE TO NEW TECHNOLOGY PACKAGE**

Item	System Description	Manufacturing: Material	Manufacturing: Labor	Manufacturing: Burden	Total Manufacturing Cost (Component/ Assembly)	Markup: End Item Scrap	Markup: SG&A	Markup: Profit	Markup: ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
	000000 Vehicle											
1	01 Engine System	$ (209.64)	$ (60.35)	$ (214.84)	$ (484.83)	$ (7.32)	$ (22.81)	$ (22.48)	$ (7.99)	$ (60.60)	$ (1.58)	$ (547.00)
2	02 Transmission System	$ 518.23	$ 191.68	$ 258.22	$ 968.13	$ 10.95	$ 68.39	$ 77.46	$ 42.68	$ 199.47	$ 1.66	$ 1,169.27
3	03 Body System	$ 7.87	$ 0.07	$ (1.82)	$ 6.12	$ (0.00)	$ (0.02)	$ (0.02)	$ 0.08	$ 0.03	$ 0.17	$ 6.31
4	06 Brake System	$ 99.45	$ 41.35	$ 55.03	$ 195.83	$ 1.70	$ 18.14	$ 15.48	$ 5.12	$ 40.45	$ 0.40	$ 236.68
5	09 Exhaust System (Included In Engine Downsizing Credit)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
6	12 Climate System	$ 152.04	$ 10.21	$ 22.67	$ 184.91	$ 1.53	$ 10.94	$ 10.93	$ 5.00	$ 28.39	$ 0.15	$ 213.46
7	14 Electrical Power Supply System	$ 1,351.10	$ 180.47	$ 287.75	$ 1,819.31	$ 13.88	$ 123.34	$ 132.13	$ 62.70	$ 332.05	$ 3.44	$ 2,154.80
8	18 Electrical Distribution and Control System	$ 127.00	$ 32.43	$ 16.16	$ 175.58	$ 0.81	$ 10.64	$ 9.75	$ 4.03	$ 25.23	$ 0.68	$ 201.50
	VEHICLE ROLL-UP	$ 2,046.05	$ 395.85	$ 423.16	$ 2,865.06	$ 21.56	$ 208.61	$ 223.25	$ 111.61	$ 565.02	$ 4.93	$ 3,435.01

D.2 Engine System and Cost Summary Overview

D.2.1 Engine Hardware Overview

The Fusion SE is fitted with a conventional 3.0 liter V-6 (**Figure D-3**) while the Fusion Hybrid contains an Atkinson 2.5 liter I-4 cylinder engine (**Figure D-4**). Both Ford Fusion engine designs featured aluminum blocks and cylinder heads. The induction systems for both engines have Dual Overhead Cams (DOHC), Variable Valve Timing (VVT), Electronic Throttle Control (ETC), and Mass Air Flow (MAF) sensors with Intake Air Temperature (IAT) and Manifold Absolute Pressure (MAP) sensors. Another similarity was the use of single-stage composite intake manifolds and intake routing paths originating behind the drivers headlamp bucket. Both engines have Port Fuel Injection (PFI) and Coil on Plug (COP) ignition (I4 has a single knock sensor, V6 has dual knock sensors).

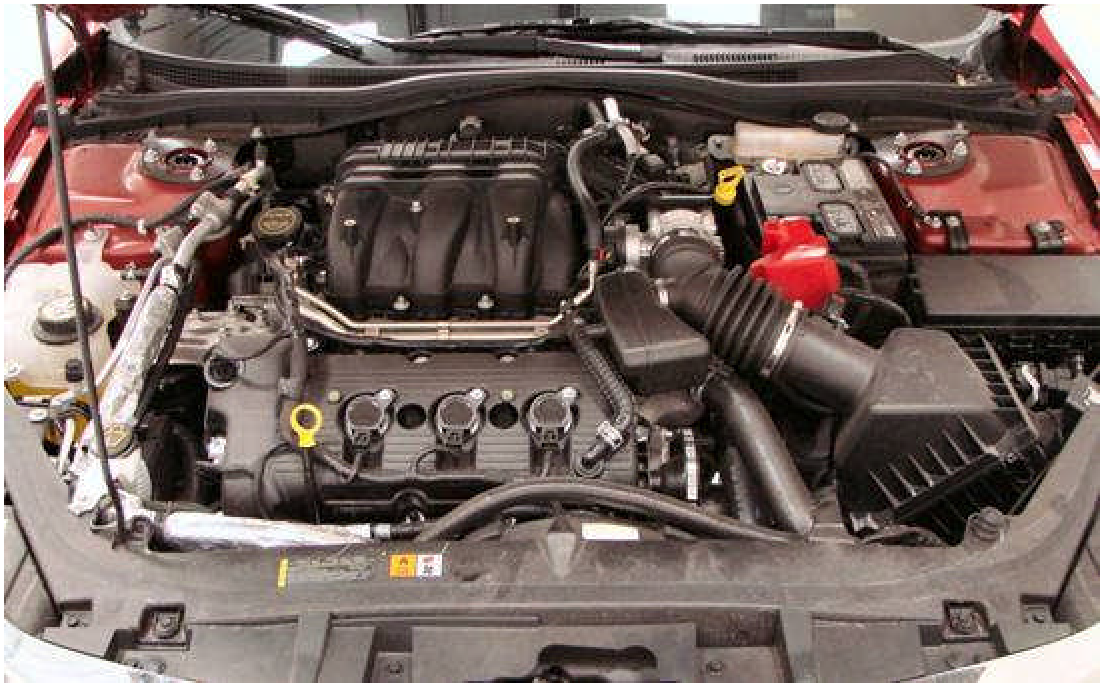


Figure D-3: 3.0L-V6 installation (Fusion SE)

Aside from displacement and cylinder configurations, differences between the two (2) engines were found in the valve train: the 3.0L-V6 used direct-acting mechanical buckets and the 2.5L-I4 utilized roller-finger follower type lifters. Compression ratios also differed: the 3.0L-V6 was 10.3:1 while the 2.5L-V6 was 12.3:1. Also, as is common in most hybrid vehicles, the 2.5L-I4 was an Atkinson-Cycle engine for increased efficiency.

Figure D-4: 2.5L-I4 installation (Fusion Hybrid)

D.2.2 Engine System Cost Impact

In the Ford Fusion Hybrid cost analysis, an internal combustion engine (ICE) downsizing credit was realized when comparing the V6 ICE in the Fusion SE to the I4 ICE in the Fusion HEV. Since a V6 to I4 downsizing credit was established by FEV in a prior EPA cost analysis (Reference http://www.epa.gov/otaq/climate/420r10010.pdf, Case Study #0102), the hardware in the two (2) Fusion vehicles was not costed. Instead the credit of $547 (established in case study #0102) was uploaded into the Fusion cost analysis, minimizing redundant efforts. As a precautionary measure, the 2.5L I4 Atkinson Cycle engine was disassembled and evaluated for potential modifications driven by the adaptation of power-split HEV technology. None were found.

D.3 Transmission System and Cost Summary Overview

D.3.1 Transmission Hardware Overview

For the transmission analysis, a 6-speed conventional automatic transmission (AT), representative of the hardware found in the baseline Ford Fusion, was evaluated against the electronic continuous variable transmission (eCVT) found in the Fusion power-split HEV. The 6-speed AT hardware present in the Fusion baseline vehicle was not used in the analysis since surrogate cost data from a prior transmission case study already existed (Reference http://www.epa.gov/otaq/climate/420r10010.pdf, Case Study #0902). In this prior analysis, the Toyota Camry Aisin 6-Speed AT (U660E) was evaluated against the Volkswagen Jetta Sport Wagon Wet Dual Clutch Transmission (DCT).

The Toyota Aisin 6-speed FWD transmission (U660E) employs a Ravigneaux and underdrive planetary gear set, positioned along a common intermediate shaft assembly. Only six (6) shift elements are required for operation of the transmission: two (2) disc clutches, three (3) disc brakes, and one (1) one-way-clutch. The U660E valve body assembly also contains a total of seven (7) shift solenoid valves interfacing with an exterior-mount transmission control module (TCM), which in turn communicates with the engine control module (ECM). The total weight of the transmission, including ATF, is 208 lbs. The maximum output torque rating for the U660E is 295 lb.-ft. Shown in **Figure D-5** is the Aisin transmission prior to disassembly.

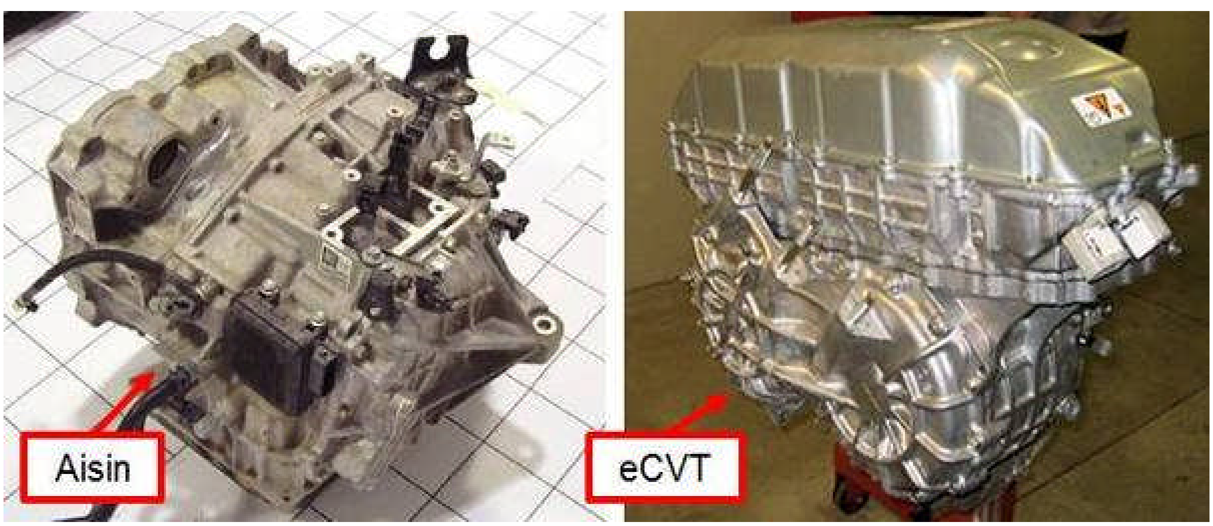


Figure D-5: Aisin 6-Speed and Fusion eCVT

The Fusion Hybrid transaxle assembly, also shown in **Figure D-5**, is an electronic continuous variable transmission (eCVT). The eCVT utilizes the input from an ICE, an electric traction motor, and electric generator. The three (3) inputs are controlled by electronics packaged within the transaxle. Power is synchronized through a singular planetary using the sun gear, controlled by the generator, to control the variability. The hybrid transmission has a separate cooling system with coolant, pump, heat exchanger, and reservoir.

D.3.1.1 Case Subsystem

The hybrid transmission structure is comprised of four (4) main castings (**Figure D-6**). The castings are fastened together with M8 and M6 threaded fasteners and sealed with RTV. All case sections are die cast aluminum designs and have extensive machining. The cases capture the powertrain components similarly to a standard transmission. Top-down assembly is used, utilizing the rear cover to locate the rear bearings. Shims and spacers are used to account for the tolerance stack-up.

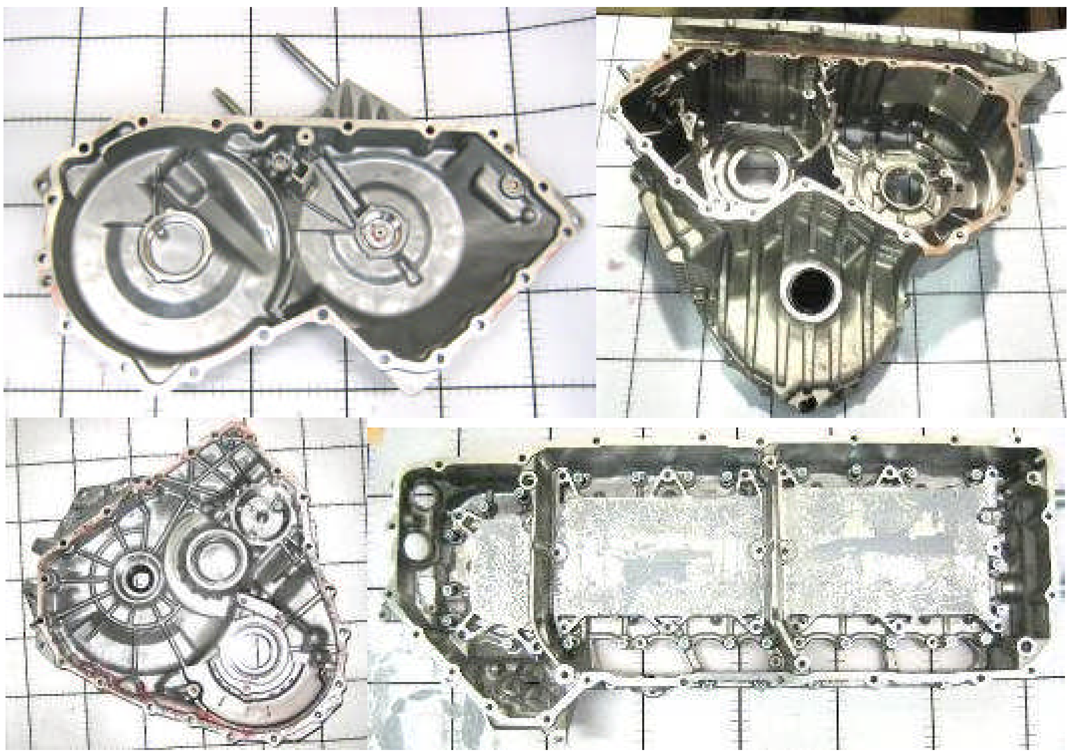


Figure D-6: Main eCVT Case Components

D.3.1.2 Gear Train Subsystem

The power-flow for the hybrid transmission is outlined in **Figure D-7**. The three (3) main inputs in the transmission are the traction motor, generator, and ICE. They are combined to create a continuously variable transmission (**Figure D-8**) utilizing a singular planetary set. The sun gear speed and direction is controlled by the generator motor. The ring gear is linked to the traction motor via the transfer main transfer gear. The input from the ICE drives the planet carrier. The transmission gear ratio is controlled precisely.

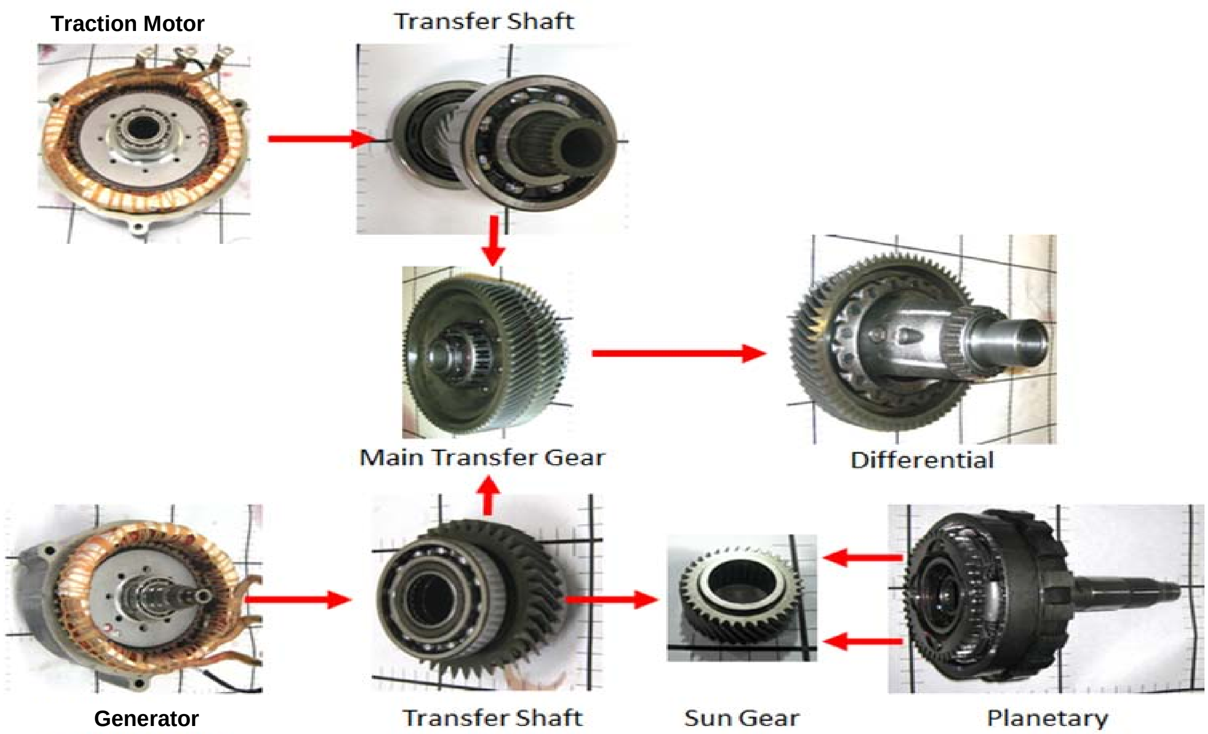


Figure D-7: Transmission Power-Flow

The traction motor and generator are controlled and powered by the electronics on the transmission. The differential is a typical automotive design and transfers power to the wheels.

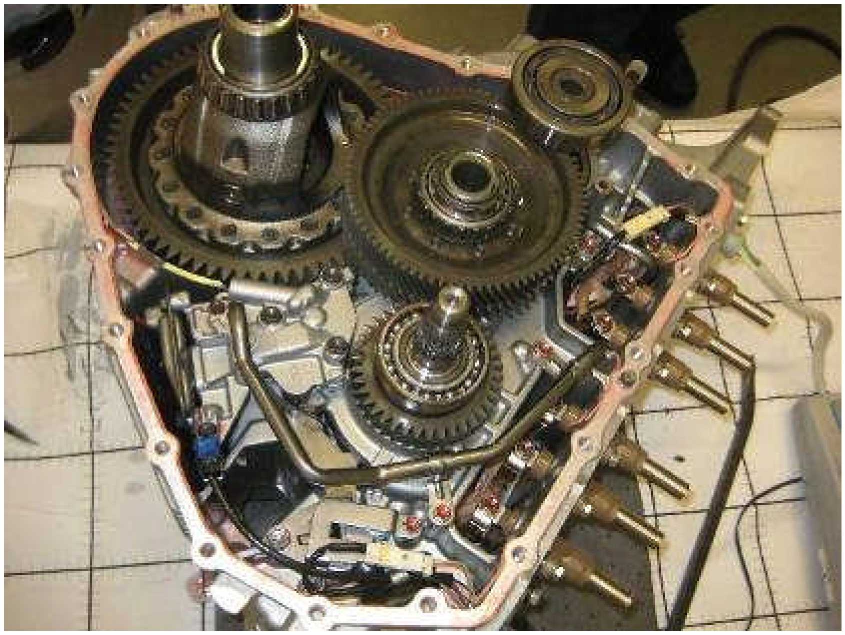


Figure D-8: Transmission Components, Installed

D.3.1.3 Electric Motor and Controls Subsystem

The generator rotor assembly (**Figure D-9**) contains thirty-two (32) rare earth magnets secured into sixteen (16) slots along the outer edge of the rotating assembly. Two hundred thirty-four (234) stamped steel plates are captured between two (2) end plates and aligned on the shaft with two (2) keyed slots. The magnets, end plates, and stamped steel plates are secured on the shaft with a large nut.

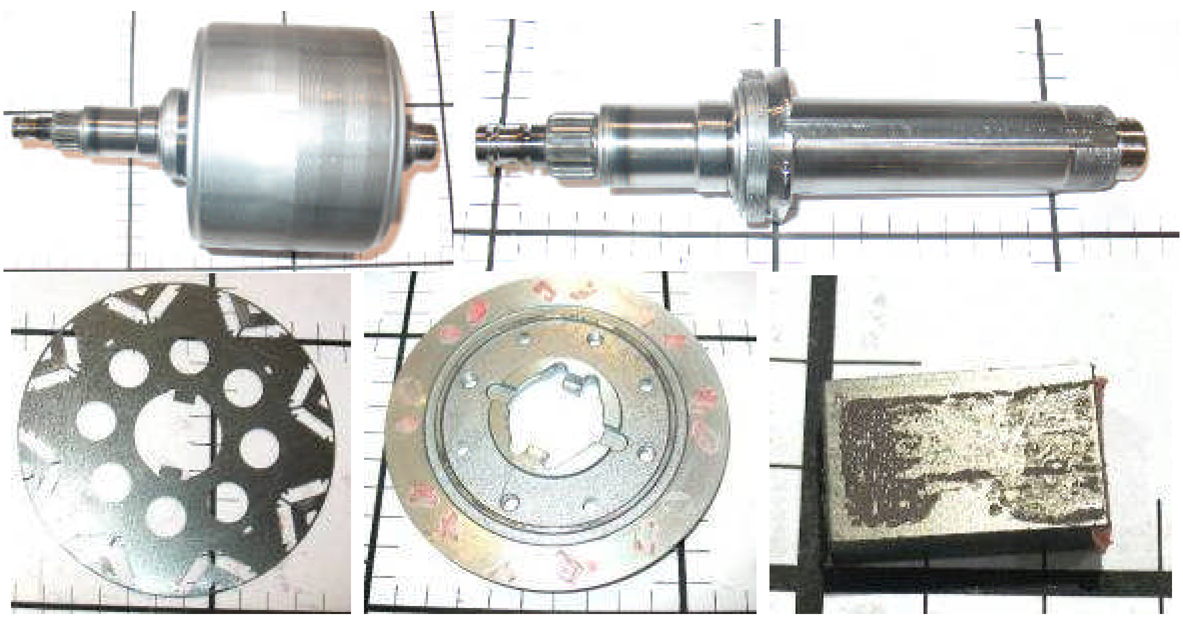


Figure D-9: Generator Rotor Components

The generator stator (**Figure D-10**) is fastened to the case with three (3) large fasteners. Three (3) wire leads extend into the transmission case. The wire leads connect to the generator control unit. The stator assembly is comprised of two hundred fifty-two (252) stamped steel plates, copper wire, insulating tube, lacing, aromatic polyamide insulators, and paint. The steel plates are welded together after stacking and assembly. A thermocouple and harness for temperature sensing are also included in the assembly.

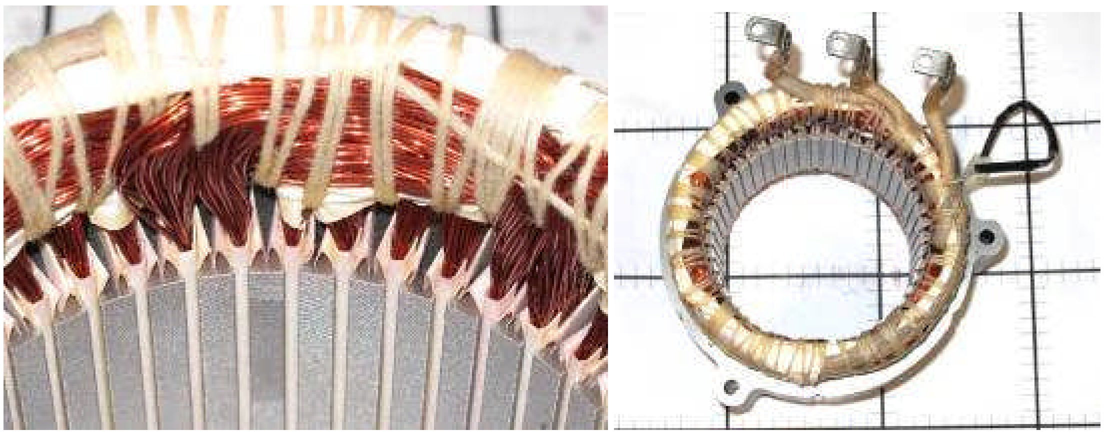


Figure D-10: Generator Stator

The traction motor rotor assembly (**Figure D-11**) is built up similarly to the generator rotor, only larger. It contains sixty-four (64) rare earth magnets that are secured in sixteen (16) slots along the outer edge of the rotating assembly. Two hundred ninety-two (292) stamped steel plates are captured between two (2) end plates and aligned on the shaft with two (2) keyed slots. The magnets, end plates, and stamped steel plates are secured on the shaft with a large nut.

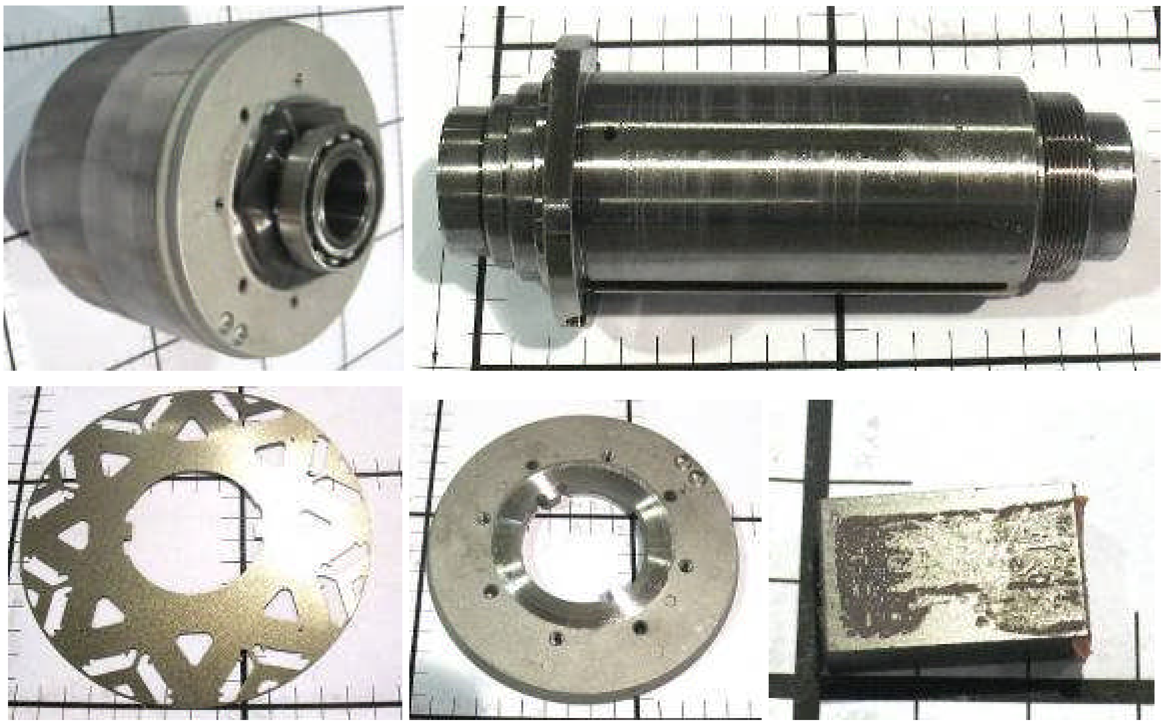


Figure D-11: Traction Motor Rotor Components

The traction motor stator (**Figure D-12**) also is similar in construction and mounting of, yet larger than, the corresponding generator stator. The stator's wire leads are connected to the traction motor control unit. The stator assembly is comprised of two hundred eighty-eight (288) stamped steel plates, copper wire, insulating tube, lacing, aromatic polyamide insulators, and paint. The stacked steel plates, once assembled, are welded together. A thermocouple is also included in this assembly.

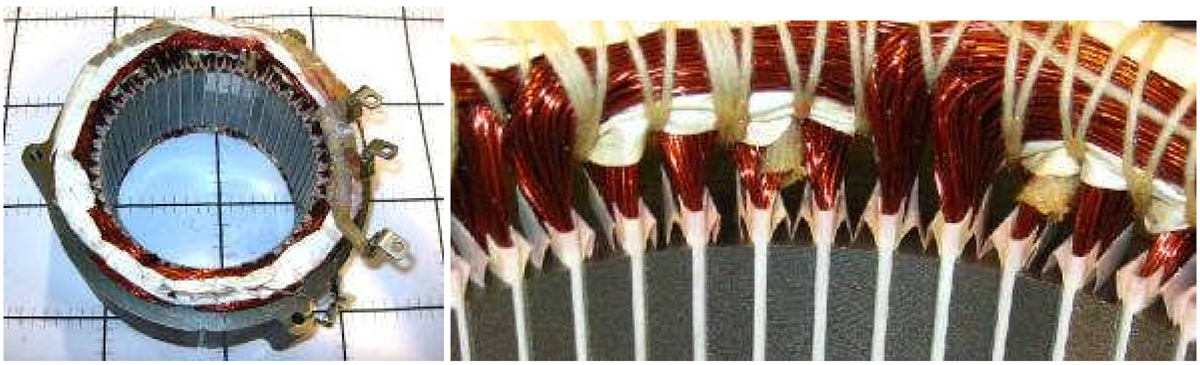


Figure D-12: Traction Motor Stator

The traction motor control unit (**Figure D-13**) contains six (6) Mitsubishi smart Insulated Gate Bipolar Transistor (IGBT) power modules and a control circuit board assembly. Two (2) transfer blocks are built-up of stamped circuit traces and then over-molded to link the IGBT high current leads together. Each of the IGBT's twelve (12) control leads is soldered to the control circuit board. The IGBT mounting faces consist of coated copper for effective heat transfer to the transaxle case. The cover, circuit board, and base plate are secured together using several threaded fasteners and studs.

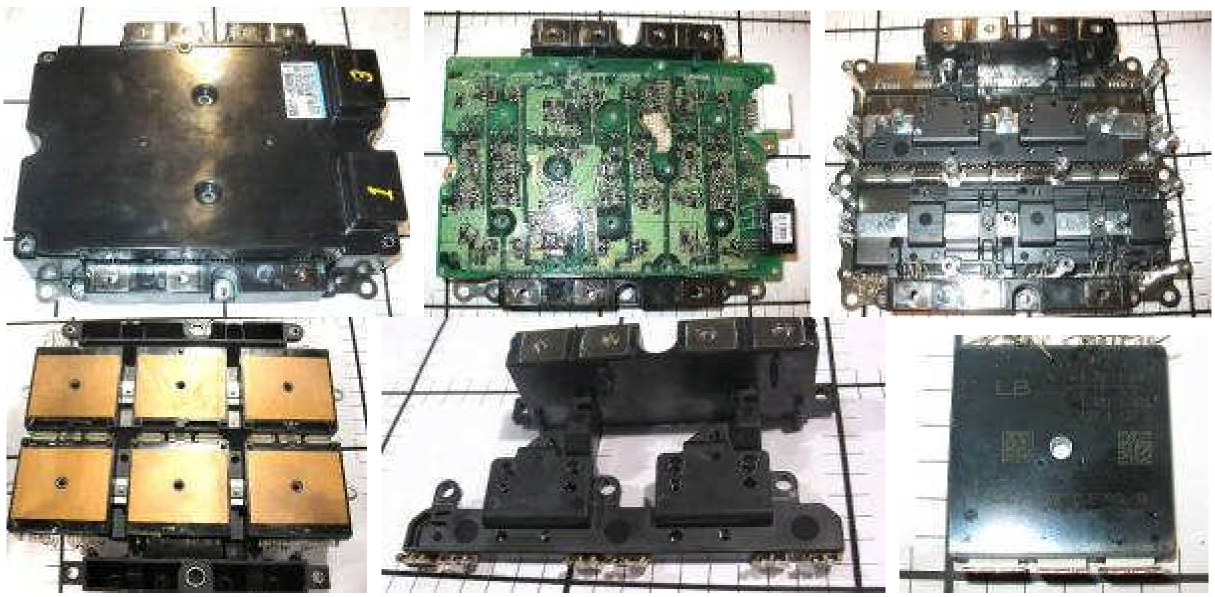


Figure D-13: Traction Control Unit Components

The generator control unit (**Figure D-14**) is different from the traction motor control unit in that it contains only five (5) Mitsubishi IGBT power modules and an additional aluminum heat sink. Similar to the motor controls section, a circuit board and two (2) transfer blocks connect the various IGBT leads together. All mounting of the power modules and control portions are identical to the motor section.

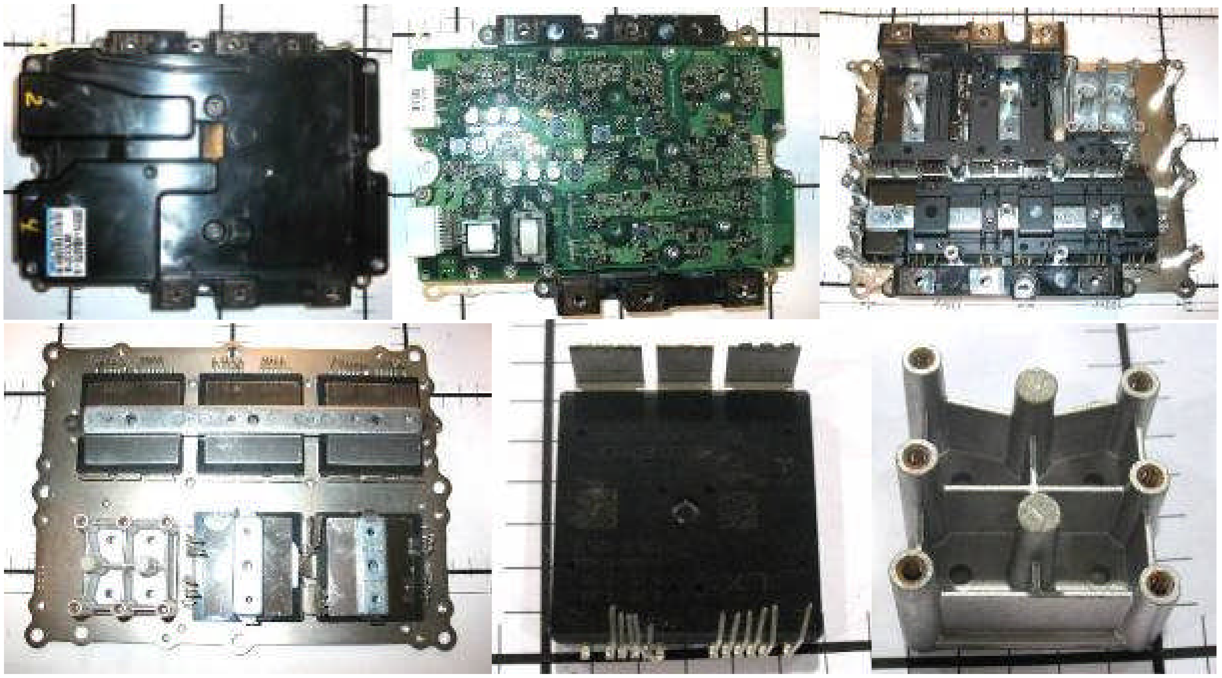


Figure D-14: Generator Control Unit Components

The control module (**Figure D-15**) is assembled to the transmission as a large subassembly. The control module consists of an aluminum frame, two (2) large capacitors, an electrical filter, a ballast resistor, and the CVT control circuit board.

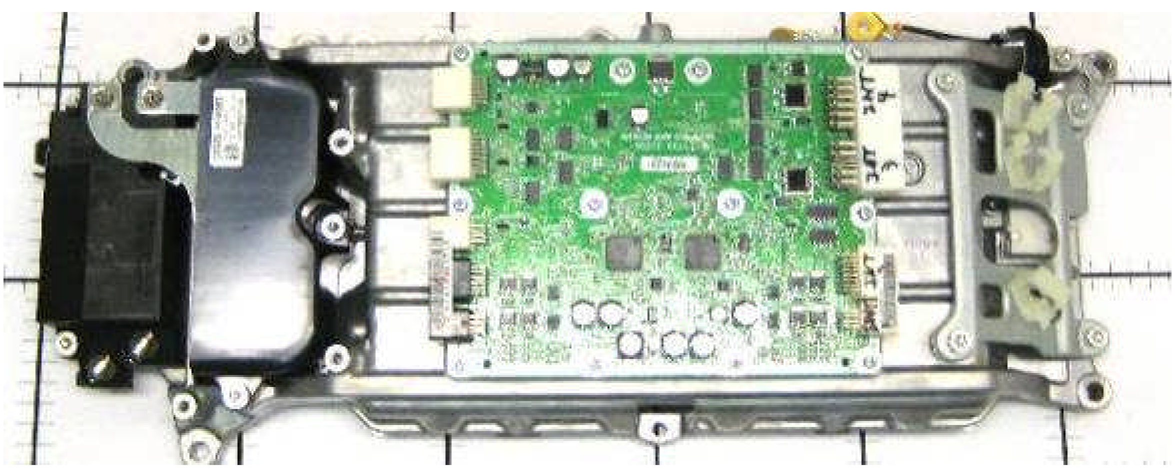


Figure D-15: Transmission Control Module

Both capacitors (**Figure D-16** and **Figure D-17**) are fastened to the control module with threaded fasteners. The small capacitor had two (2) large leads that connected directly to the filter. The large capacitor utilized six (6) large leads to connect to both control units and the smaller capacitor.

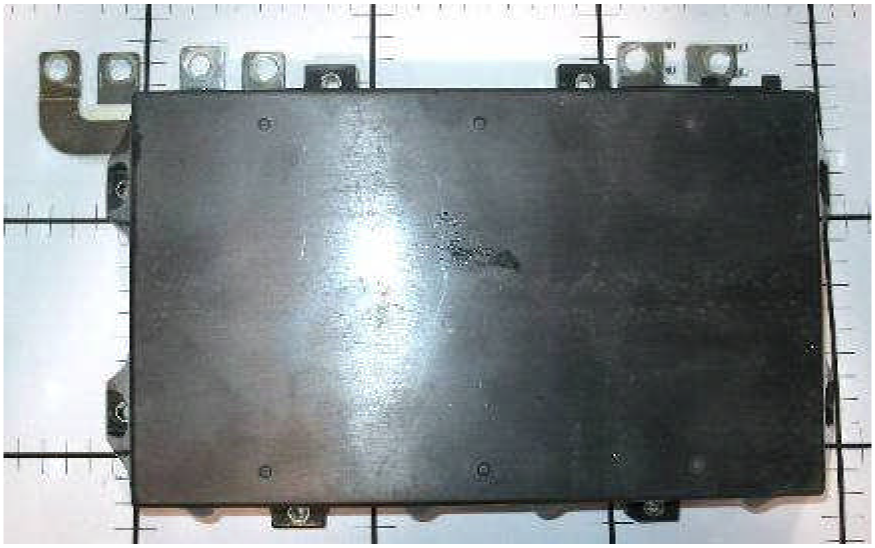


Figure D-16: Large Capacitor

Figure D-17: Small Capacitor

The CVT control circuit board (**Figure D-18**) is fastened to the control module housing with twelve (12) threaded fasteners. This circuit board contains seven (7) connector ports that link to the control units, current sensors, temperature sensors, and external ports.

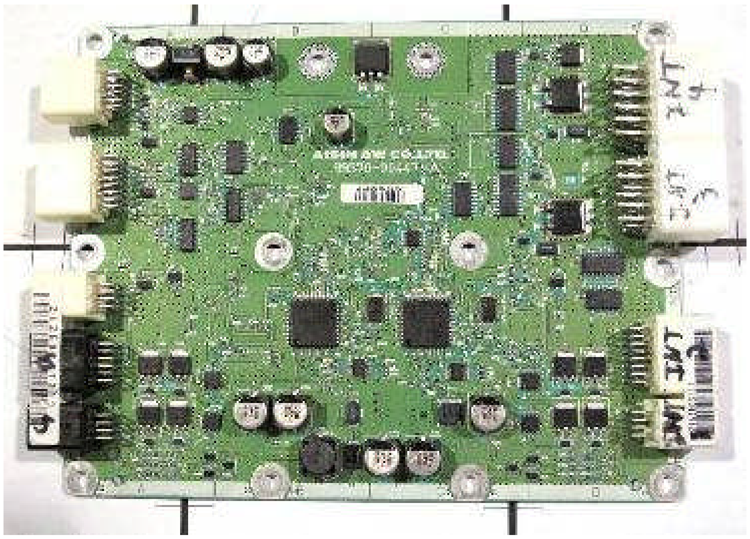


Figure D-18: CVT Control Circuit Board

The housing for the transmission control module (**Figure D-19**) is a large die cast aluminum part with a minimal amount of machining. The housing fits the capacitors, filter, CVT circuit board, and ballast resistor together into a large, compacted assembly.

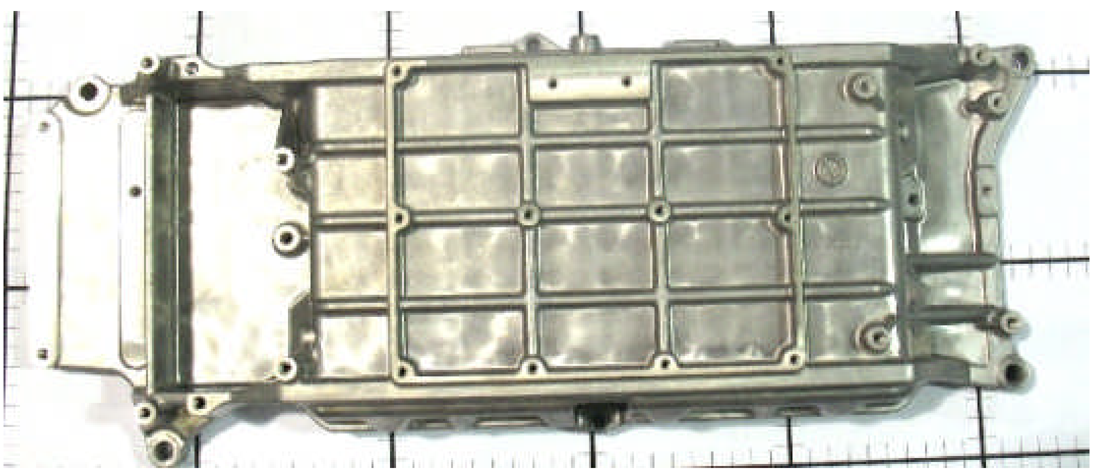


Figure D-19: Housing, Transmission Control Module

The electrical filter and ballast resistor (**Figure D-20**) are secured to the transmission control module with threaded fasteners. The electrical filter is connected to the high voltage power input and the smaller capacitor.

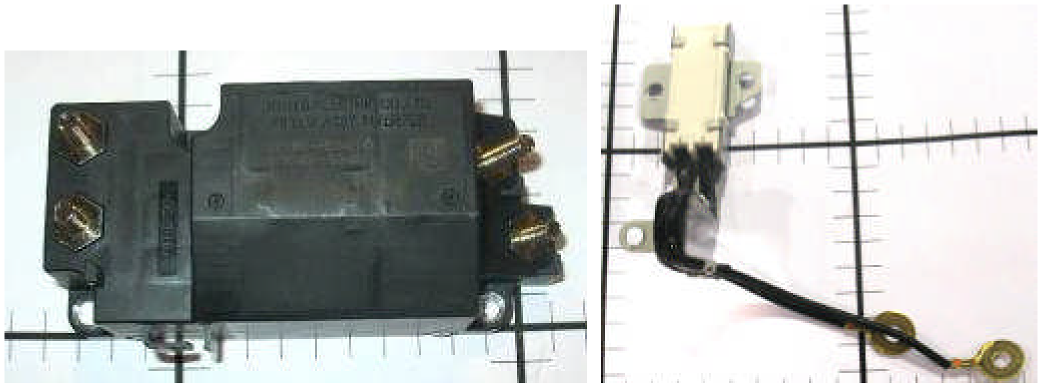


Figure D-20: Electrical Filter, Inverter and Ballast Resistor

Both generator and traction motor are monitored by speed sensors for velocity, acceleration, and direction. Both sensors have three (3) copper wire circuits wrapped around the individual poles. The laminate plates are dimpled so that they lock once the stack is pressed together. Both sensors are over-molded with integrated electrical connectors. Individual speed sensor harnesses are used to connect between the control modules and sensors.

The generator sensor (**Figure D-21**) has fourteen (14) poles and seven (7) stamped steel laminate plates.

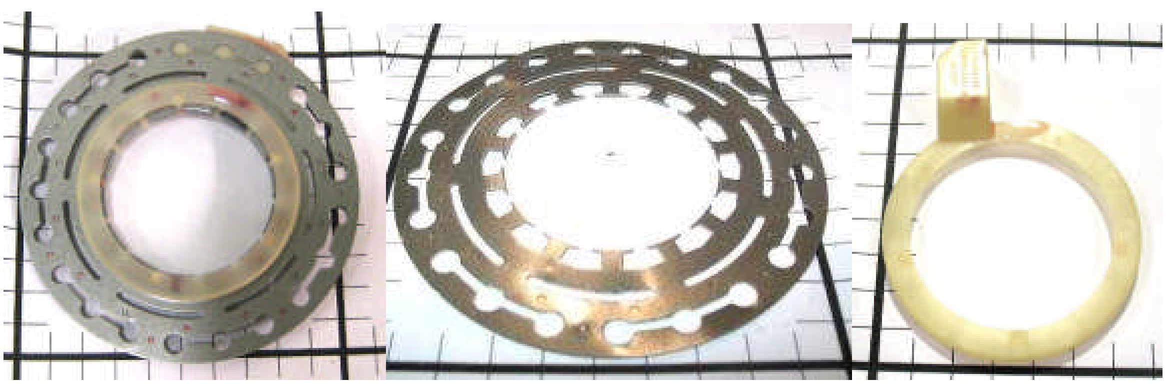


Figure D-21: Speed Sensor, Generator

The speed sensor for the traction motor (**Figure D-22**) uses sixteen (16) poles and eight (8) stamped steel laminate plates.

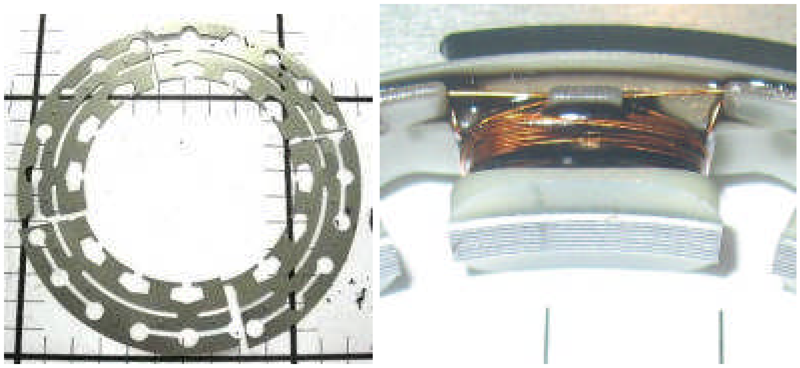


Figure D-22: Speed Sensor, Traction Motor

Two (2) current sensor assemblies are utilized for monitoring the traction motor and generator current flow (**Figure D-23**). Each sensor assembly contains three (3) individual measuring circuits corresponding with the traction motor and generator wiring. Each lead from the motor and generator goes through a dedicated hole in the sensor assembly. The sensor assemblies are secured to the lower portion of the transmission case with two (2) threaded fasteners.

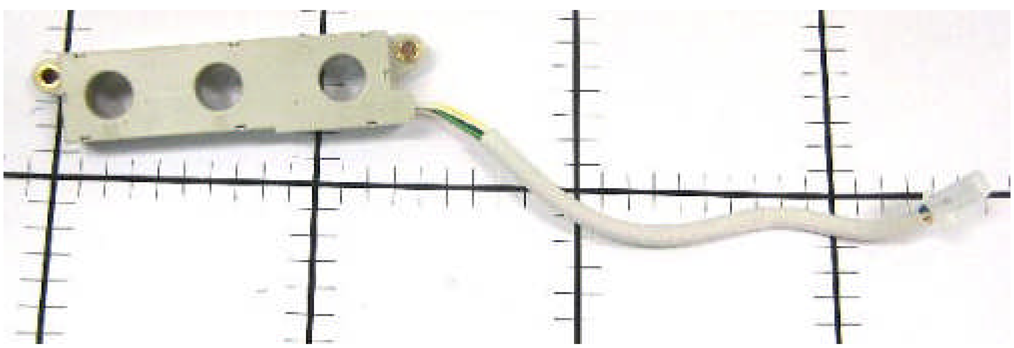


Figure D-23: Current Sensor Assembly

The coil module assembly is connected directly to the lower transmission assembly with four (4) fasteners. Large electrical leads, from the bus bar, connect the coil module to the power circuit. A temperature sensor is embedded in the potting of the coil module. Note the sensor's harness lead and connector in **Figure D-24**.

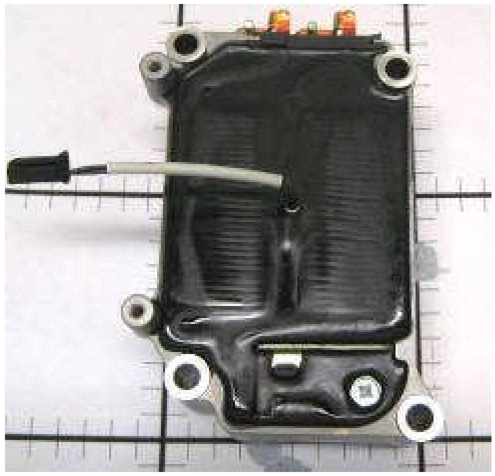


Figure D-24: Coil Module Assembly

Six (6) harnesses (**Figure D-25**) link the various electronic components together. Many of the sensors and electrical components contain their own harnesses.

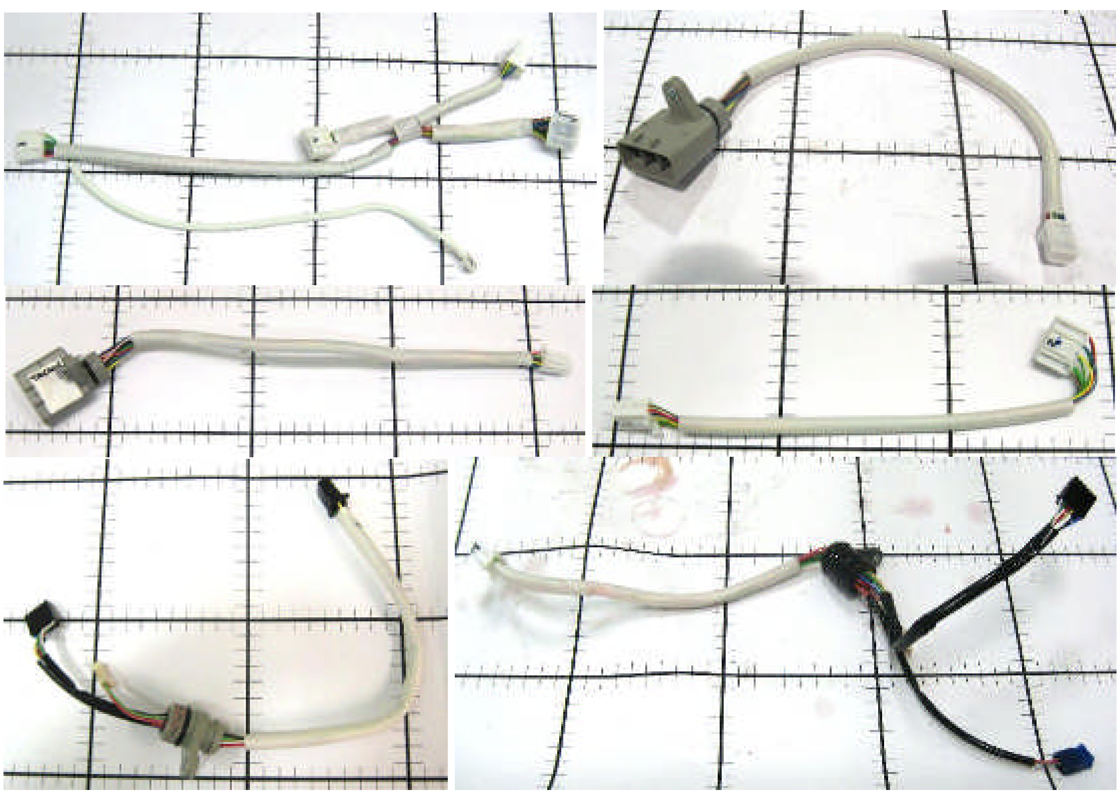


Figure D-25: Transmission Harnesses

D.3.1.4 Transmission Cooling System

D.3.1.4.1 Transaxle Cooling System (Baseline Fusion)

The baseline transaxle (**Figure D-26**) is cooled by routing the transmission fluid though an externally mounted heat exchanger. Fluid is forced through the heat exchanger by the internal transmission pump. The heat exchanger (**Figure D-27**) is a traditional design mounted internal to the radiator tank.

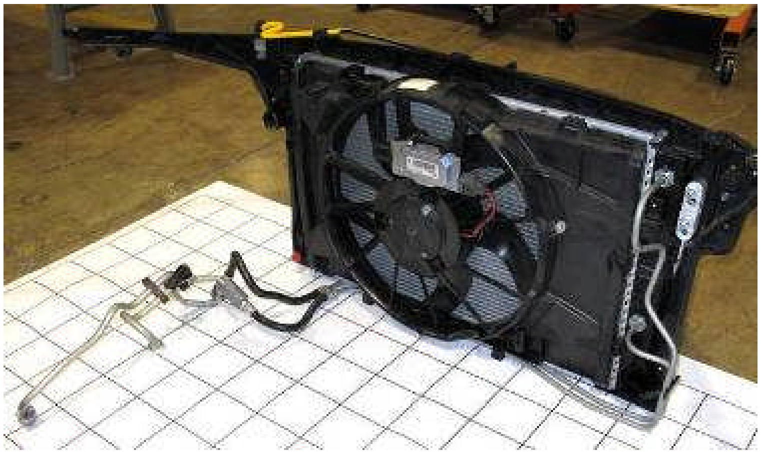


Figure D-26: Cooler Lines and Radiator with Internal Cooler

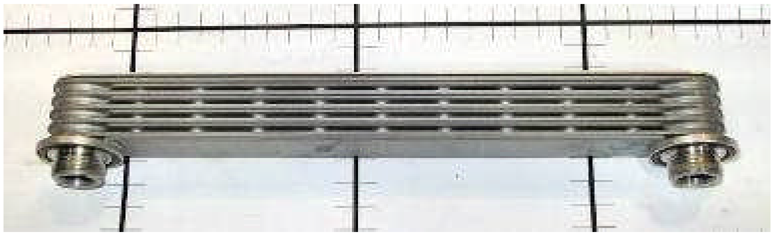


Figure D-27: Internal Cooler

D.3.1.4.2 Transaxle Cooling System (Fusion HEV)

An auxiliary coolant pump is attached in-line on the cooling system for the transmission control module and DC-DC converter. This pump circulates coolant from the electronics associated with the hybrid drive and moves it to the exchanger. The exchanger is mounted external to the radiator ahead of the AC condenser (**Figure D-28** and **Figure D-29**).

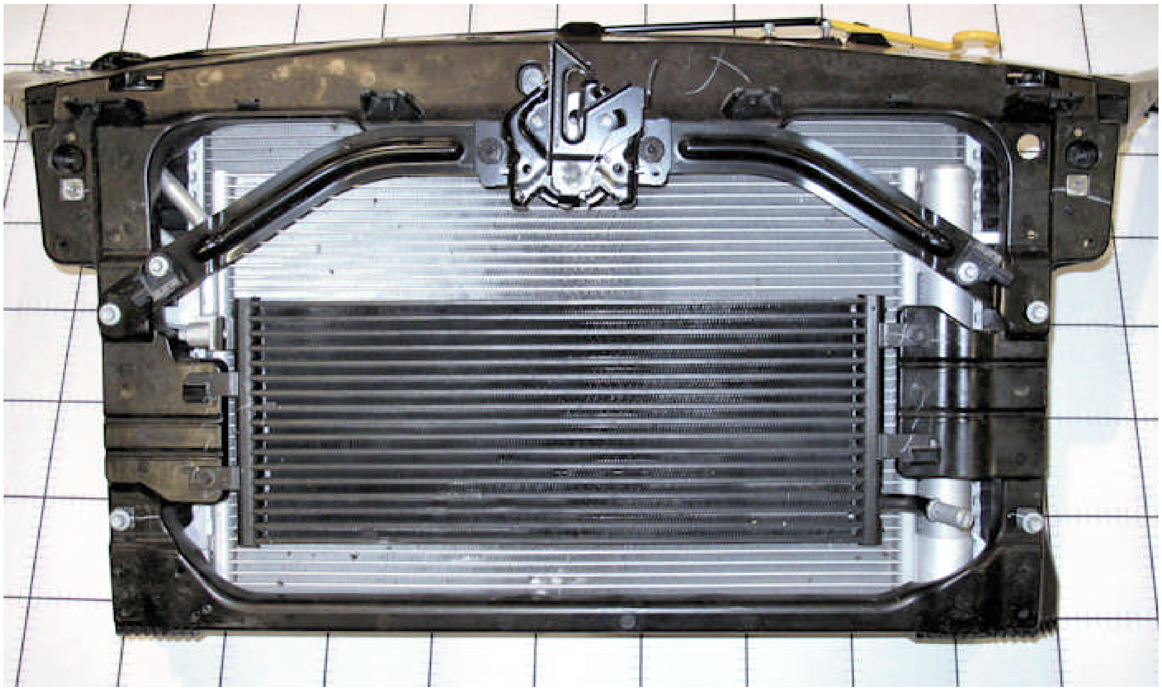


Figure D-28: Exchanger Mounted to Front End Module (FEM)

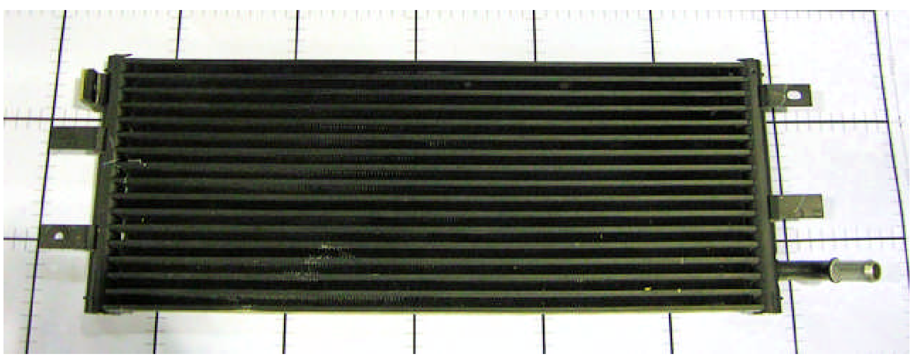


Figure D-29: Exchanger on Bench

The electric pump (**Figure D-30**) is isolation mounted to the front radiator core support. Coolant lines are attached with two (2) standard spring clamps. Since the system was separate from the engine cooling system a separate reservoir was employed.

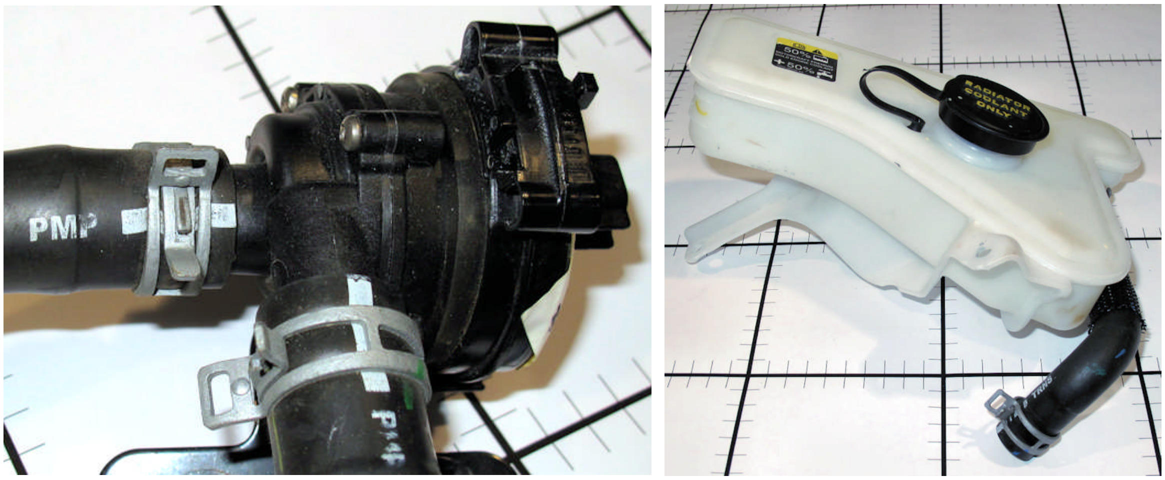


Figure D-30: Auxiliary Coolant Pump with Mount, Hoses, Spring Clamps & Reservoir

The coolant routing through the hybrid transmission serves two (2) purposes; it cools the power electronics, and extracts energy from the transmission fluid. The heat exchanger, partially integrated into the Housing – Electronic Assembly (**Figure D-31**), provides a physical boundary between the two (2) main functional sections of the transmission. The top section – or “electrical section” – houses all the power electronics and controls. The bottom section – or “mechanical section” – houses the gearing, traction motor, generator, and other miscellaneous associated hardware.

On the “electrical section” of the transmission, coolant running through the heat exchanger cools the power electronics mounted to the top side of the heat exchanger. Thermal conductive paste is used under each component to maximize heat transfer (**Figure D-32**).

On the bottom side of the heat exchanger, which is partially integrated into the transaxle case – main subassembly, transmission fluid is cooled as it flows through the bottom chamber. Cooled transmission fluid leaving the heat exchanger is then circulated to key components within the transmission, including the main planetary set, bearings, traction motor, and generator.

Figure D-31: Internal Heat Exchanger, Integrated into the Bottom Side of the Housing – Electronic Assembly

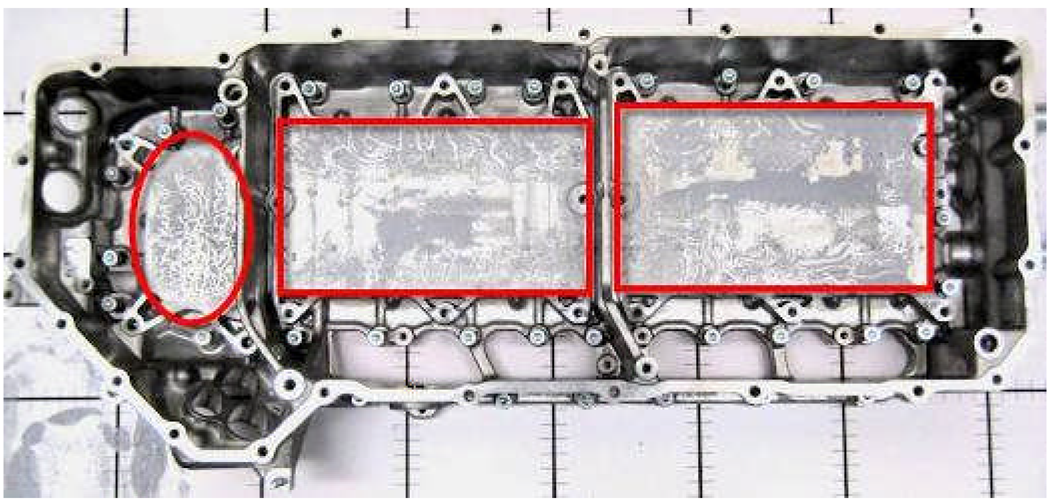


Figure D-32: Mounting Face for Power Electronics on Top Side of Housing – Electronic Assembly

D.3.2 Transmission System Cost Impact

Relative to the baseline 6-speed AT, the new eCVT increased in cost by approximately 212% ($1,169) (i.e., Baseline 6-speed AT Incremental = $1,047, HEV eCVT Incremental = $2216).

Note: As covered in the process methodology discussion, only component differences (i.e., additions, deletions, modifications) driven by the new technology adaptation are evaluated for cost impact. If component differences exist, as examined in the baseline and new technology configuration, and the differences are independent of the new technology adaptation (i.e., driven by supplier or OE design preference, vehicle packaging, etc.), no cost considerations are given.

Occasionally, where component differences do exist (driven by new technology adaptation), and there is content and/or function similarities with offsetting component value, the cost analysis efforts are reduced or eliminated. These types of offsetting cost estimations are judiciously applied and are generally limited to commodity type components (e.g. pumps, sensors, solenoids).

In the Transmission System Cost Model Analysis Template (CMAT), **Table D-5**, the net incremental direct manufacturing cost of the Ford Fusion electronic continuous variable transmission (eCVT) over the baseline 6-speed automatic transmission is shown. In the system level CMAT, the incremental costs for each major subsystem, if applicable, are shown for both the new technology (Ford Fusion HEV) and base technology (Ford Fusion SE). The subsystem costs for the new technology are subtracted from the base technology, resulting in the net incremental direct manufacturing cost for each subsystem. The subsystem incrementals are rolled up into a net system incremental cost, while maintaining cost element resolution.

From the net incremental direct manufacturing cost of $1,169.27, approximately 83% ($968.13) of the costs are total manufacturing costs (TMCs) and 17% are mark-up costs. From the $968.13 in TMCs, approximately 53.5% ($518.23) of the added cost comes from materials, 19.8% ($191.68) from labor, and 26.7% ($258.22) in manufacturing overhead.

For the conventional 6-speed transmission the majority of the costs are shared across five (5) or six (6) of the traditional automatic transmission subsystems (e.g., cases, geartrain, internal clutches, launch clutches, electrical controls). In contrast more than 70% ($1,602.54) of the eCVT costs are associated with electric motor and controls subsystem.

Table D-6 is a subsystem CMAT drilling down further into the cost make-up of the electric motors and controls subsystem for the eCVT. The top three (3) sub-subsystems, which make-up over 80% of the subsystem costs, are:

1. Traction motor and generator (37.8% of subsystem costs)
2. Power electronic components and assemblies (12.1% of subsystem costs)
    a. sub-subsystem mainly comprised of large passive power electronic components
3. Control modules (33.3% of subsystem costs)
    a. sub-subsystem comprised of motor control unit (MCU), generator control unit (GCU), and transmission control unit (TCU)
    b. Both low- and high-voltage MCU and GCU components included in module.
    c. Single, low-voltage TCU board only

Table D-5: Net Incremental Direct Manufacturing Cost of Ford Fusion HEV eCVT in Comparison to Conventional 6-Speed Automatic Transmission

SYSTEM & SUBSYSTEM DESCRIPTION		NEW TECHNOLOGY GENERAL PART INFORMATION: 2010 Ford Fusion HEV, 2.5L Atkinson Cycle, I4, 156hp (191 Net), (NiMH Battery 275V, Nominal Pack Capacity 5.5Ah, 1.51kWh)										
		Manufacturing			Total Manufacturing Cost (Component/ Assembly)	Markup				Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
Item	System/Subsystem Description	Material	Labor	Burden		End Item Scrap	SG&A	Profit	ED&T-R&D			
	020000 Transmission System											
1	02 Case Subsystem	$ 85.05	$ 16.43	$ 81.14	$ 182.62	$ 4.90	$ 7.97	$ 8.82	$ 2.10	$ 23.79	$ 1.97	$ 208.39
2	03 Gear Train Subsystem	$ 74.98	$ 21.74	$ 37.08	$ 133.80	$ 1.31	$ 14.84	$ 13.45	$ 4.13	$ 33.74	$ 0.41	$ 167.95
3	04 Internal Clutch Subsystem	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
4	05 Launch Clutch Subsystem	$ 20.93	$ 11.40	$ 15.35	$ 47.67	$ 0.51	$ 1.96	$ 1.81	$ 0.30	$ 4.59	$ 0.24	$ 52.51
5	06 Oil Pump and Filter Subsystem	$ 2.52	$ 1.77	$ 3.68	$ 7.97	$ 0.33	$ 0.54	$ 0.50	$ 0.21	$ 1.56	$ 0.05	$ 9.58
6	07 Mechanical Controls Subsystem	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
7	08A Electrical Controls Subsystem	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
8	08B Transmission Control Module (Est. $150)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
9	09 Parking Mechanism Subsystem	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
10	10 Misc Subsystem	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
11	11 Electric Motor & Controls Subsystem	$ 793.95	$ 208.98	$ 337.24	$ 1,340.17	$ 10.01	$ 96.40	$ 103.22	$ 49.50	$ 259.12	$ 3.25	$ 1,602.54
12	12 Transmission Cooling System	$ 32.91	$ 13.04	$ 13.89	$ 59.84	$ 0.40	$ 5.85	$ 4.93	$ 1.55	$ 12.74	$ 0.24	$ 72.82
13	13 OE Transmission Assembly (broke out for eCVT only, included in subsystem roll-ups in base analysis)	$ -	$ 58.49	$ 44.17	$ 102.66	$ -	$ -	$ -	$ -	$ -	$ -	$ 102.66
		$ 1,010.34	$ 331.85	$ 532.55	$ 1,874.73	$ 17.46	$ 127.56	$ 132.73	$ 57.79	$ 335.54	$ 6.16	$ 2,216.43

SYSTEM & SUBSYSTEM DESCRIPTION		BASE TECHNOLOGY GENERAL PART INFORMATION: 2010 Ford Fusion SE, 3.0L V6, 4-Val. DOHC, NA, PFI, 240hp, 223lb*ft										
		Manufacturing			Total Manufacturing Cost (Component/ Assembly)	Markup				Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
Item	System/Subsystem Description	Material	Labor	Burden		End Item Scrap	SG&A	Profit	ED&T-R&D			
	020000 Transmission System											
1	02 Case Subsystem	$ 59.04	$ 10.47	$ 45.95	$ 115.46	$ 0.55	$ 7.18	$ 6.62	$ 2.76	$ 17.11	$ 0.56	$ 133.12
2	03 Gear Train Subsystem	$ 47.93	$ 42.72	$ 91.92	$ 182.57	$ 2.92	$ 16.39	$ 14.85	$ 2.35	$ 36.51	$ 0.69	$ 219.77
3	04 Internal Clutch Subsystem	$ 54.86	$ 37.85	$ 67.45	$ 160.16	$ 1.57	$ 16.17	$ 16.15	$ 4.81	$ 38.70	$ 2.81	$ 201.67
4	05 Launch Clutch Subsystem	$ 89.44	$ 0.46	$ 0.83	$ 90.74	$ -	$ -	$ -	$ -	$ -	$ -	$ 90.74
5	06 Oil Pump and Filter Subsystem	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
6	07 Mechanical Controls Subsystem	$ 15.44	$ 31.49	$ 41.23	$ 88.16	$ 0.59	$ 7.66	$ 7.07	$ 1.18	$ 16.50	$ 0.26	$ 104.92
7	08A Electrical Controls Subsystem	$ 104.86	$ 3.94	$ 6.01	$ 114.82	$ 0.02	$ 0.24	$ 0.22	$ 0.04	$ 0.51	$ 0.01	$ 115.34
8	08B Transmission Control Module (Est. $150)	$ 115.34	$ 3.24	$ 11.02	$ 129.60	$ 0.65	$ 8.49	$ 7.84	$ 3.24	$ 20.23	$ 0.17	$ 150.00
9	09 Parking Mechanism Subsystem	$ 0.30	$ 1.02	$ 0.72	$ 2.03	$ 0.01	$ 0.12	$ 0.14	$ 0.10	$ 0.38	$ -	$ 2.41
10	10 Misc Subsystem	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
11	11 Electric Motor & Controls Subsystem	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
12	12 Transmission Cooling System	$ 4.89	$ 8.99	$ 9.19	$ 23.06	$ 0.19	$ 2.92	$ 2.38	$ 0.64	$ 6.14	$ -	$ 29.20
13	13 OE Transmission Assembly (broke out for eCVT only, included in subsystem roll-ups in base analysis)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
		$ 492.10	$ 140.17	$ 274.33	$ 906.60	$ 6.51	$ 59.17	$ 55.27	$ 15.12	$ 136.07	$ 4.49	$ 1,047.17

SYSTEM & SUBSYSTEM DESCRIPTION		INCREMENTAL COST TO UPGRADE TO NEW TECHNOLOGY PACKAGE										
Item	System/Subsystem Description	Manufacturing: Material	Manufacturing: Labor	Manufacturing: Burden	Total Manufacturing Cost (Component/ Assembly)	Markup: End Item Scrap	Markup: SG&A	Markup: Profit	Markup: ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
	020000 Transmission System											
1	02 Case Subsystem	$ 26.01	$ 5.96	$ 35.19	$ 67.17	$ 4.35	$ 0.79	$ 2.20	$ (0.65)	$ 6.68	$ 1.41	$ 75.26
2	03 Gear Train Subsystem	$ 27.05	$ (20.98)	$ (54.84)	$ (48.77)	$ (1.61)	$ (1.55)	$ (1.39)	$ 1.78	$ (2.77)	$ (0.29)	$ (51.83)
3	04 Internal Clutch Subsystem	$ (54.86)	$ (37.85)	$ (67.45)	$ (160.16)	$ (1.57)	$ (16.17)	$ (16.15)	$ (4.81)	$ (38.70)	$ (2.81)	$ (201.67)
4	05 Launch Clutch Subsystem	$ (68.51)	$ 10.93	$ 14.51	$ (43.06)	$ 0.51	$ 1.96	$ 1.81	$ 0.30	$ 4.59	$ 0.24	$ (38.23)
5	06 Oil Pump and Filter Subsystem	$ 2.52	$ 1.77	$ 3.68	$ 7.97	$ 0.33	$ 0.54	$ 0.50	$ 0.21	$ 1.56	$ 0.05	$ 9.58
6	07 Mechanical Controls Subsystem	$ (15.44)	$ (31.49)	$ (41.23)	$ (88.16)	$ (0.59)	$ (7.66)	$ (7.07)	$ (1.18)	$ (16.50)	$ (0.26)	$ (104.92)
7	08A Electrical Controls Subsystem	$ (104.86)	$ (3.94)	$ (6.01)	$ (114.82)	$ (0.02)	$ (0.24)	$ (0.22)	$ (0.04)	$ (0.51)	$ (0.01)	$ (115.34)
8	08B Transmission Control Module (Est. $150)	$ (115.34)	$ (3.24)	$ (11.02)	$ (129.60)	$ (0.65)	$ (8.49)	$ (7.84)	$ (3.24)	$ (20.23)	$ (0.17)	$ (150.00)
9	09 Parking Mechanism Subsystem	$ (0.30)	$ (1.02)	$ (0.72)	$ (2.03)	$ (0.01)	$ (0.12)	$ (0.14)	$ (0.10)	$ (0.38)	$ -	$ (2.41)
10	10 Misc Subsystem	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
11	11 Electric Motor & Controls Subsystem	$ 793.95	$ 208.98	$ 337.24	$ 1,340.17	$ 10.01	$ 96.40	$ 103.22	$ 49.50	$ 259.12	$ 3.25	$ 1,602.54
12	12 Transmission Cooling System	$ 28.03	$ 4.06	$ 4.70	$ 36.78	$ 0.21	$ 2.93	$ 2.55	$ 0.91	$ 6.60	$ 0.24	$ 43.62
13	13 OE Transmission Assembly (broke out for eCVT only, included in subsystem roll-ups in base analysis)	$ -	$ 58.49	$ 44.17	$ 102.66	$ -	$ -	$ -	$ -	$ -	$ -	$ 102.66
		$ 518.23	$ 191.68	$ 258.22	$ 968.13	$ 10.95	$ 68.39	$ 77.46	$ 42.68	$ 199.47	$ 1.66	$ 1,169.27

Table D-6: eCVT Motor and Controls Subsystem Cost Breakdown

Item	SYSTEM & SUBSYSTEM DESCRIPTION System/Subsystem Description	NEW TECHNOLOGY GENERAL PART INFORMATION: 2010 Ford Fusion HEV, 2.5L Atkinson Cycle, I4, 156hp (191 Net), (NiMH Battery 275V, Nominal Pack Capacity 5.5Ah, 1.51kWh) Manufacturing Material	Labor	Burden	Total Manufacturing Cost (Component/ Assembly)	Markup End Item Scrap	SG&A	Profit	ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
	021100 Electric Motor & Controls Subsystem											
1	01 Traction and Generator Motors	$ 197.55	$ 115.46	$ 193.46	$ 506.47	$ 3.55	$ 35.45	$ 40.52	$ 20.26	$ 99.77	$ 0.28	$ 606.52
2	02 Power Electronic Components and Assemblies	$ 107.30	$ 17.57	$ 32.74	$ 157.61	$ 1.49	$ 15.19	$ 13.68	$ 5.84	$ 36.20	$ 0.45	$ 194.26
3	03 Control Modules	$ 400.05	$ 17.07	$ 27.49	$ 444.61	$ 3.10	$ 31.04	$ 35.48	$ 17.74	$ 87.37	$ 1.16	$ 533.13
4	04 Traction and Generator Motor Sensors	$ 26.67	$ 17.96	$ 20.02	$ 64.66	$ 0.36	$ 4.22	$ 3.93	$ 1.75	$ 10.26	$ 0.33	$ 75.24
5	05 Internal Electrical Connections (e.g.wire harness, terminals, bus	$ 23.39	$ 31.05	$ 18.39	$ 72.83	$ 0.36	$ 4.72	$ 4.33	$ 1.77	$ 11.19	$ 0.20	$ 84.22
6	10 Plugs	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
7	15 Switches	$ 0.67	$ 1.06	$ 0.80	$ 2.53	$ 0.01	$ 0.16	$ 0.15	$ 0.06	$ 0.39	$ 0.03	$ 2.95
8	72 Electrical Housings/Support Structure	$ 35.11	$ 7.36	$ 43.28	$ 85.76	$ 1.12	$ 5.28	$ 4.88	$ 2.02	$ 13.30	$ 0.70	$ 99.75
9	75 Brackets	$ 1.94	$ 1.14	$ 0.53	$ 3.61	$ 0.01	$ 0.19	$ 0.12	$ 0.03	$ 0.35	$ 0.10	$ 4.06
10	80 Boltings	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
11	85 Sealing Elements	$ 1.26	$ 0.31	$ 0.52	$ 2.10	$ 0.01	$ 0.14	$ 0.13	$ 0.02	$ 0.29	$ 0.02	$ 2.41
12												
13												
14												
	SUBSYSTEM ROLL-UP	$ 793.95	$ 208.98	$ 337.24	$ 1,340.17	$ 10.01	$ 96.40	$ 103.22	$ 49.50	$ 259.12	$ 3.25	$ 1,602.54

D.4 Body System and Cost Summary Overview

D.4.1 Body Hardware Overview

Hybrid technology drives some subtle changes to the body systems. Most changes are confined to the traction battery area. The rear seat bottom is polyurethane (PUR) foam on wire frame for the base model while the hybrid model uses PUR foam on an expanded polypropylene (EPP) base. The hybrid's EPP base allows designers to use the seat as a duct for air flow. Cabin air is pulled through a vent opening in the front face of rear seat cushion and directed into the battery module via the integrated seat ducting. The cooler cabin air, which is pulled through the battery module, is exhausted into the trunk compartment. Heat shielding under the rear seat and inside the rear seat backs was also added to support cooling of the battery and to minimize heat transfer from the battery to rear passenger seat back.

Other less significant body system changes include: (1) under engine splash pans, (2) inclusion of molded trim panels in the luggage compartment to accommodate the traction battery and air flow, and (3) addition of body weld studs and nuts for mounting unique HEV components (e.g., DC-DC converter module, high voltage wire harness, and High Voltage Battery). All other portions of the body system were found to be essentially identical.

Note: In some cases, where components are added to a vehicle system to support the mounting or function of a component within another system, costs are generally captured in the system driving the need for the component. For example, weld studs and nuts are added to the body system to support the mounting of the high voltage wire harness to the vehicle. In the cost analysis, the costs of the weld studs and nuts are included in the Electrical Distribution and Electronic Control System, Traction and High Voltage Power Distribution Subsystem.

D.4.1.1 Body Closures Subsystem

D.4.1.1.1 Body Closures Subsystem

The under engine splash shield on the base Fusion deadens sound, insulates, and protects the lower engine bay and powertrain (**Figure D-33**). The hybrid Fusion's under engine splash shield (**Figure D-34**) is identical in construction and purpose to the base model. The difference between the shields in size and number of access holes which are driven by the powertrain package.

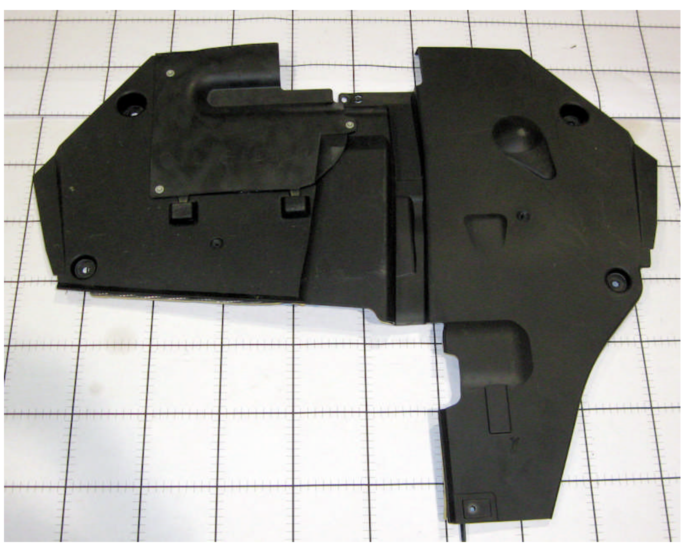


Figure D-33: Base Fusion, Under Engine Splash Shield

Figure D-34: HEV Fusion, Under Engine Splash Shield

D.4.1.2 Interior Trim and Ornamentation Subsystem

A molded trim panel is utilized in the HEV Fusion's luggage compartment to cover the traction battery. Provisions are made for warm air to exit the plenum as it is exhausted from the cooling system of the battery (**Figure D-35**).

Figure D-35: Luggage Compartment Liner

D.4.1.3 Sound and Heat Control Subsystem

Due to traction battery heat at the rear seat backs, heat shielding is inserted into the rear seat back covers. This heat shield consists of double layer bubble wrap captured between a top and bottom aluminum foil layer (**Figure D-36**).

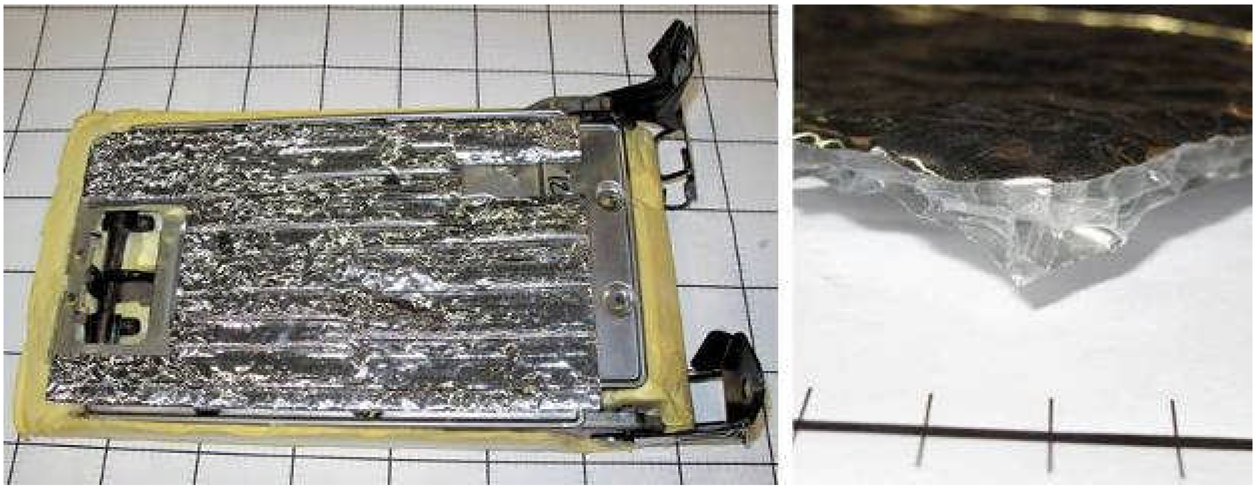


Figure D-36: Heat Shield on Rear Seat Backs

Heat shielding is also required on the rear seat pan area. This heat shield is a single layer of bubble wrap sheet covering only one (1) side with an aluminum foil. Mounting of the heat shield is accomplished via push pins to the seat pan (**Figure D-37**).

Figure D-37: Heat Shield for Rear Seat Pan

D.4.1.4 Seating Subsystem

D.4.1.4.1 Seating Subsystem (Base Fusion)

The base Fusion's rear seat bottom is a conventional design of polyurethane (PUR) foam over-molded on a bent and welded wire frame. The wire frame is used to fasten the seat base to the body. The seat cover is mounted to the foam seat base wire frame using hog rings for the majority of the fastenings with hook and loop retention on the pleated features only (**Figure D-38** through **Figure D-41**).

Figure D-38: Rear Seat Bottom (Base)

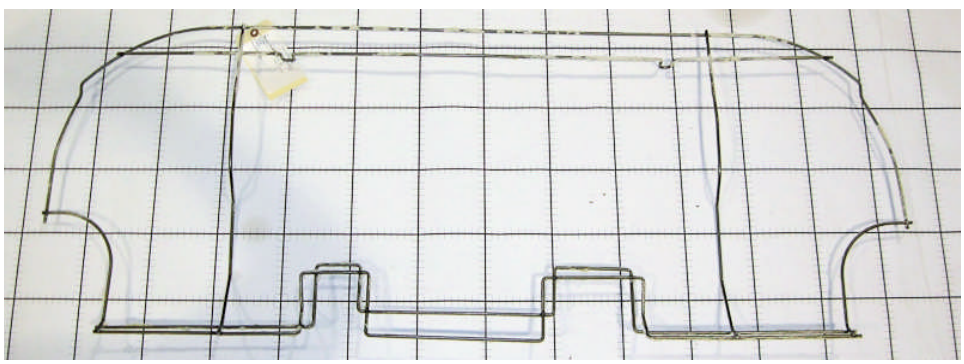


Figure D-39: Wire Frame Weldment

Figure D-40: Seat Cover Fastening Types

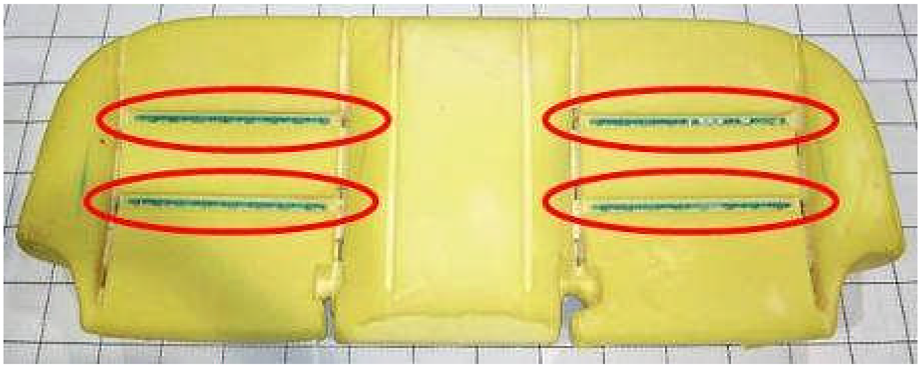


Figure D-41: Hook and Loop Placement

D.4.1.4.2 Seating Subsystem (HEV Fusion)

Due to cooling requirements of the traction battery, air is drawn from under the rear seat bottom into the battery case. To accommodate the air flow, the rear seat base structure is molded from expanded polypropylene (EPP). This allows for an air duct to be molded into the base (**Figure D-42** and **Figure D-43**). A polyurethane (PUR) foam cushion is then placed on the EPP base. Driven by the lack of a conventional wire frame for seat mounting, four (4) formed retainers and fasteners are mounted to the seat base (**Figure D-44**). The seat cover is mounted to the foam seat cover with hook and loop retention while the base employs extruded retainers which fit molded slots in the base. The extruded retainers are sewn onto the seat cover (**Figure D-45** through **Figure D-47**). To close out the seat air duct a molded plastic intake grill (**Figure D-48**) is secured with push pins to the seat base.

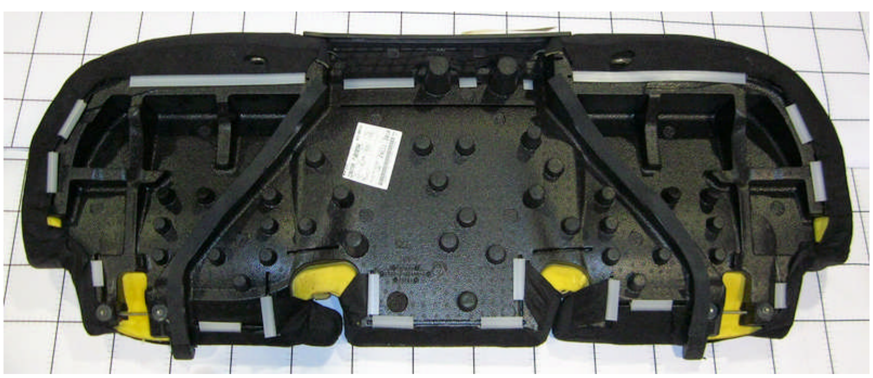


Figure D-42: Rear Seat Bottom (HEV)

Figure D-43: Expanded Polypropylene (EPP), Seat Base Structure

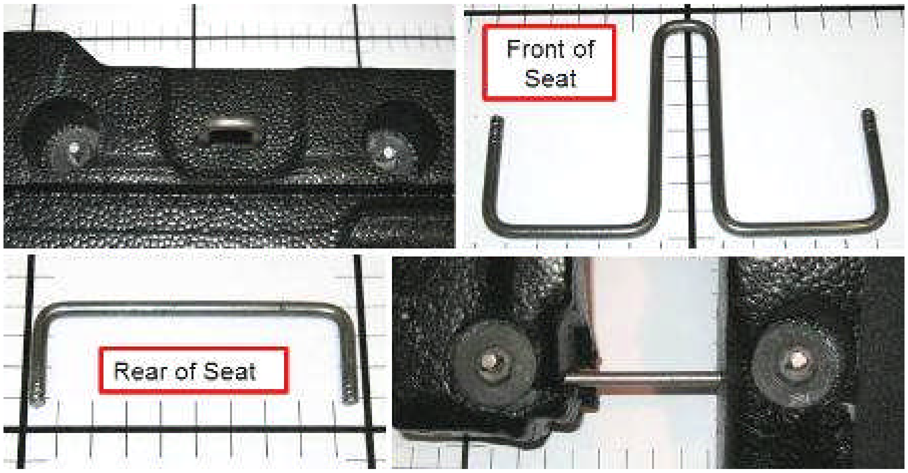


Figure D-44: Seat Retainers

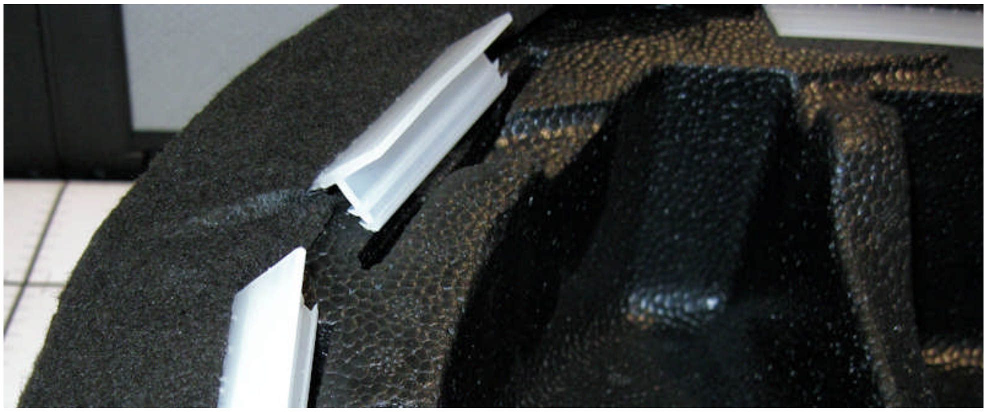


Figure D-45: Extruded Retainers for Seat Cover to Base

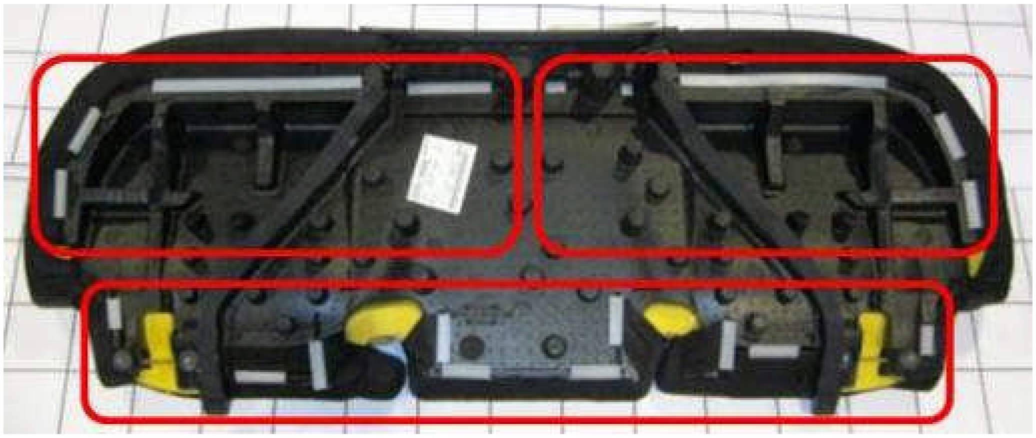


Figure D-46: Extruded Retainer location on Base

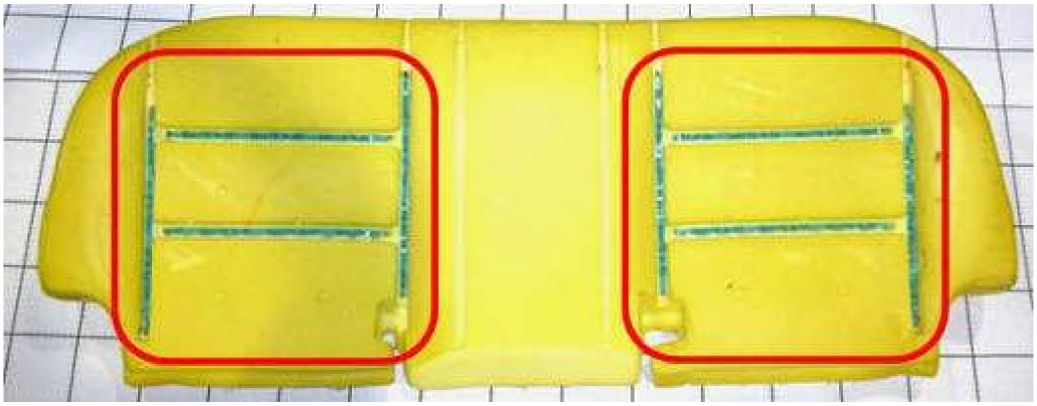


Figure D-47: Hook and Loop Placement on Cushion

Figure D-48: Intake Grill

D.4.2 Body System Cost Impact

As shown in **Table D-7**, the incremental costs are captured for each of the four (4) subsystems discussed previously. In general, the design and/or manufacturing differences between the components, within each subsystem, from each vehicle, result in a very small incremental cost difference. The net incremental direct manufacturing cost for the body system was $6.31.

Table D-7: Net Incremental Direct Manufacturing Cost of Ford Fusion HEV Body System in Comparison to Ford Fusion Base Body System

SYSTEM & SUBSYSTEM DESCRIPTION		NEW TECHNOLOGY GENERAL PART INFORMATION: 2010 Ford Fusion HEV, 2.5L Atkinson Cycle, I4, 156hp (191 Net), (NiMH Battery 275V, Nominal Pack Capacity 5.5Ah, 1.51kWh)										
Item	System/Subsystem Description	Manufacturing			Total Manufacturing Cost (Component/ Assembly)	Markup				Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
		Material	Labor	Burden		End Item Scrap	SG&A	Profit	ED&T-R&D			
	030000 Body System											
1	03 Body Closures Subsystem	$ 9.04	$ 4.24	$ 3.65	$ 16.94	$ 0.18	$ 2.24	$ 2.13	$ 0.67	$ 5.22	$ -	$ 22.16
2	05 Interior Trim and Ornamentation Subsystem	$ 4.74	$ 1.00	$ 1.03	$ 6.77	$ 0.04	$ 0.52	$ 0.48	$ 0.18	$ 1.22	$ -	$ 7.99
3	06 Sound and Heat Control Subsystem (Body)	$ 5.21	$ 3.10	$ 1.66	$ 9.98	$ 0.08	$ 1.05	$ 0.97	$ 0.32	$ 2.42	$ 0.17	$ 12.57
4	10 Seating Subsystem	$ 13.77	$ 9.76	$ 6.72	$ 30.24	$ 0.29	$ 3.83	$ 3.53	$ 1.09	$ 8.75	$ -	$ 38.99
	SUBSYSTEM ROLL-UP	$ 32.76	$ 18.10	$ 13.06	$ 63.92	$ 0.59	$ 7.64	$ 7.11	$ 2.27	$ 17.62	$ 0.17	$ 81.71

SYSTEM & SUBSYSTEM DESCRIPTION		BASE TECHNOLOGY GENERAL PART INFORMATION: 2010 Ford Fusion SE, 3.0L V6, 4-Val. DOHC, NA, PFI, 240hp, 223lb*ft										
Item	System/Subsystem Description	Manufacturing			Total Manufacturing Cost (Component/ Assembly)	Markup				Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
		Material	Labor	Burden		End Item Scrap	SG&A	Profit	ED&T-R&D			
	000000 Vehicle											
1	03 Body Closures Subsystem	$ 7.31	$ 2.75	$ 2.61	$ 12.67	$ 0.14	$ 1.69	$ 1.63	$ 0.52	$ 3.97	$ -	$ 16.64
2	05 Interior Trim and Ornamentation Subsystem	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
3	06 Sound and Heat Control Subsystem (Body)	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
4	10 Seating Subsystem	$ 17.57	$ 15.28	$ 12.28	$ 45.13	$ 0.46	$ 5.98	$ 5.51	$ 1.68	$ 13.62	$ -	$ 58.75
	SUBSYSTEM ROLL-UP	$ 24.88	$ 18.04	$ 14.89	$ 57.81	$ 0.60	$ 7.67	$ 7.13	$ 2.19	$ 17.59	$ -	$ 75.39

SYSTEM & SUBSYSTEM DESCRIPTION		INCREMENTAL COST TO UPGRADE TO NEW TECHNOLOGY PACKAGE										
Item	System/Subsystem Description	Manufacturing			Total Manufacturing Cost (Component/ Assembly)	Markup				Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
		Material	Labor	Burden		End Item Scrap	SG&A	Profit	ED&T-R&D			
	030000 Body System											
1	03 Body Closures Subsystem	$ 1.73	$ 1.49	$ 1.04	$ 4.26	$ 0.04	$ 0.55	$ 0.51	$ 0.16	$ 1.26	$ -	$ 5.52
2	05 Interior Trim and Ornamentation Subsystem	$ 4.74	$ 1.00	$ 1.03	$ 6.77	$ 0.04	$ 0.52	$ 0.48	$ 0.18	$ 1.22	$ -	$ 7.99
3	06 Sound and Heat Control Subsystem (Body)	$ 5.21	$ 3.10	$ 1.66	$ 9.98	$ 0.08	$ 1.05	$ 0.97	$ 0.32	$ 2.42	$ 0.17	$ 12.57
4	10 Seating Subsystem	$ (3.81)	$ (5.53)	$ (5.56)	$ (14.89)	$ (0.16)	$ (2.15)	$ (1.97)	$ (0.58)	$ (4.87)	$ -	$ (19.76)
	SUBSYSTEM ROLL-UP	$ 7.87	$ 0.07	$ (1.82)	$ 6.12	$ (0.00)	$ (0.02)	$ (0.02)	$ 0.08	$ 0.03	$ 0.17	$ 6.31

D.5 Brake System and Cost Summary Overview

D.5.1 Brake Hardware Overview

A brake-by-wire brake system replaces the conventional brake system found on the baseline Ford Fusion vehicle. In the brake-by-wire system the traditional brake pedal module is replaced with an actuation unit consisting of a pedal feel simulator and rotary position sensor to pick-up driver commands. Signals from the actuation sensor, along with various other sensors directly related to vehicle braking, are delivered electrically to an electronic control unit. Under normal braking conditions, the electric generator is "turned on," converting vehicle braking energy into electric power which is stored in the high voltage traction battery. When the generator-provided deceleration is insufficient, the electronic control unit will activate the hydraulic control unit, and potentially the vacuum pump, which in turn builds up the necessary hydraulic pressure to operate the conventional wheel brakes.

In addition to a unique pedal actuation mechanism and the added vacuum pump, an enhanced booster containing a vacuum control solenoid and position sensor were required. The hydraulic systems on both vehicles, from the master cylinders to the wheels, were considered cost neutral.

It is acknowledged that the brake-by-wire system provided by Continental Automotive for the Fusion HEV is one of many available brake system options that may be used in an HEV or EV application. The system is perhaps more expensive than others in the market that are not considered true brake-by-wire. However, based on the stated advantages of the brake-by-wire (**Figure D-49**), and the growing industry trend toward increased electronic actuation and controls (e.g., drive-by-wire, electronic power steering), the team felt the technology configuration was a good choice for the application.

More details regarding the difference between the two (2) brake systems and associated costs are captured in the following discussion.

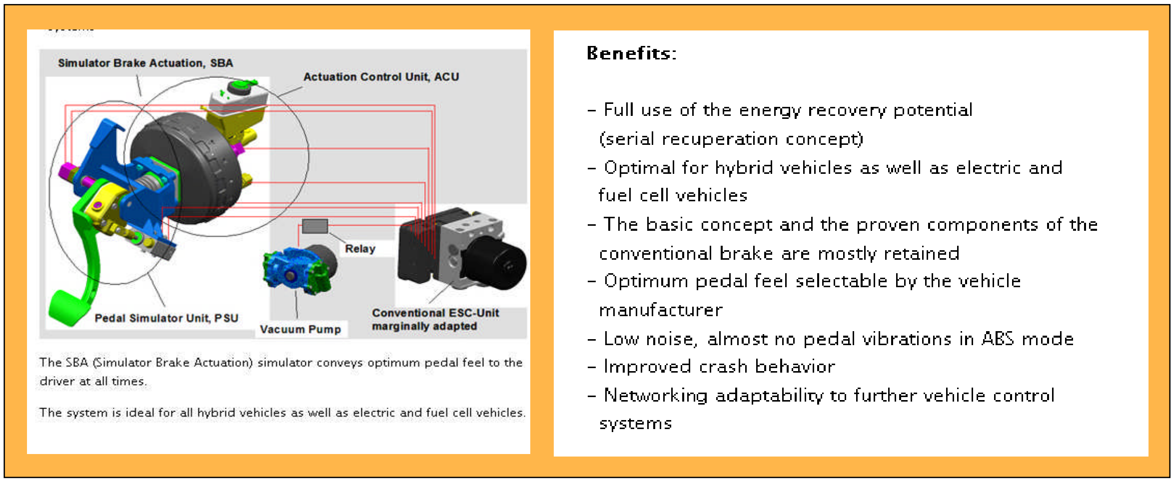


Figure D-49: Key Components of Brake-By-Wire System

(Source of information contained in this figure - Continental Automotive Web page "Regenerative Brake System"
http://www.conti-online.com/generator/www/de/en/continental/automotive/themes/passenger_cars/chassis_safety/ebs/extended_functions/brems_systeme_en.html

D.5.1.1 Brake Actuation Subsystem

D.5.1.1.1 Brake Actuation Subsystem (Base Fusion)

The pedal and bracket assembly – brake (**Figure D-50**) on the base vehicle consists of a conventional multi-piece stamped steel bracket, stamped pedal arm, pedal plate, and pedal pivot hub. A pivot shaft secures the pedal arm assembly to the bracket. There is an added switch bracket and flag for mounting and actuating the brake on/off switch, respectively. The pedal arm has a stamped clevis hole which provides the mechanical connection to the brake booster.

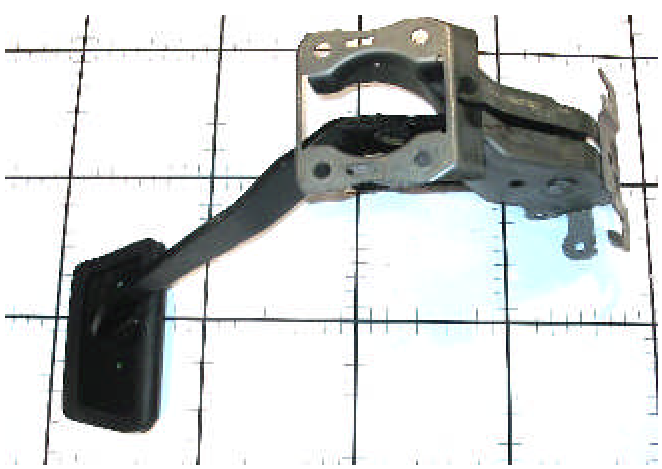


Figure D-50: Brake Pedal Assembly (Base Fusion)

D.5.1.1.2 Brake Actuation Subsystem (Hybrid Fusion)

The hybrid brake pedal and sensor assembly – brake (**Figure D-51**), by nature of its added function, is more complex than the base pedal and bracket assembly. The pedal bracket is a cast aluminum design containing traditional features (e.g., switch bracket mounting, pedal arm mounting) as well as new features required for brake-by-wire (e.g., rotary position sensor mounting, brake actuator solenoid mounting). The brake arm contains a modified clevis attachment, a travel stop, and a feature to drive the brake simulator and position sensor. The position sensor provides the driver commanded brake signal. The simulator provides the reactionary load to the driver simulating traditional brake system efforts as would be experienced in a mechanical system. The actuator provides the fail-safe function allowing the brake actuation system to revert back to a conventional mechanical system. The rotary position sensor, actuator, and simulator are shown in **Figure D-52**.

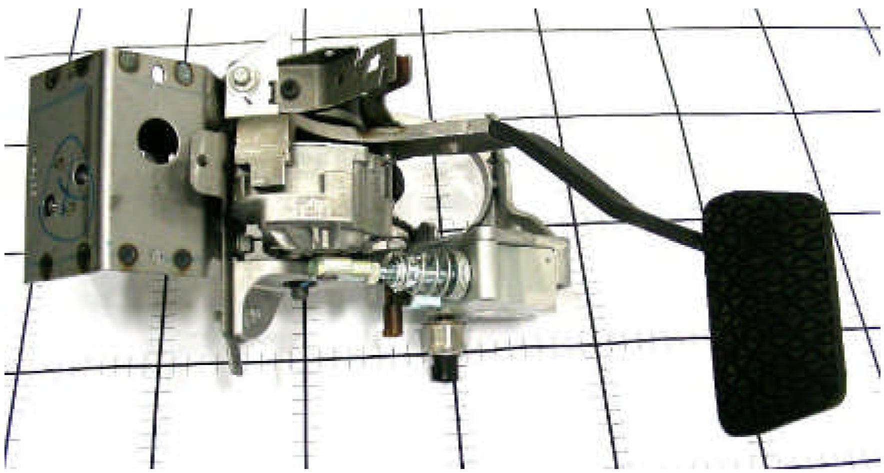
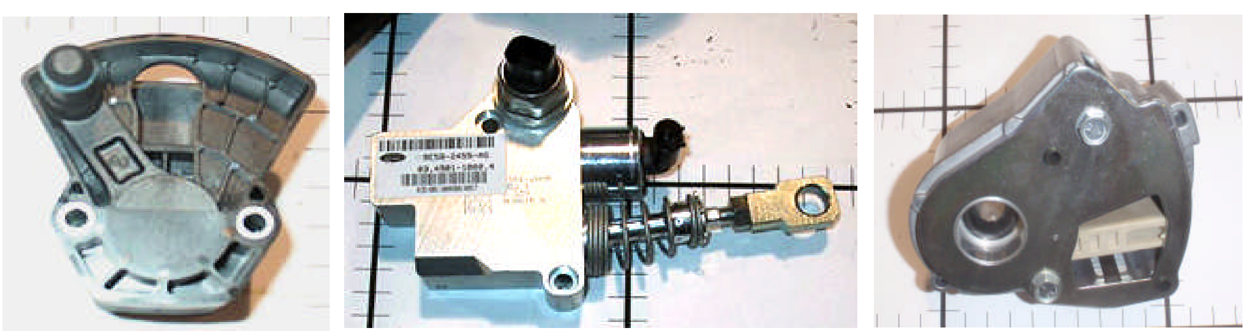


Figure D-51: Brake Pedal Assembly (HEV Fusion)



1. Rotary Position Sensor **2. Actuator** **3. Simulator**

Figure D-52: Additional Components Added to the Pedal & Bracket Assembly – Brake for a Brake-By-Wire System

D.5.1.2 Power Brake Subsystem

D.5.1.2.1 Vacuum Booster (Base Fusion)

The base vehicle utilizes a typical single diaphragm vacuum booster (**Figure D-53**). This booster consists of two (2) stamped shells front and rear. The forward face provides features for attaching the master cylinder and vacuum supply port. The rear shell mounts to the dash panel and is secured to the pedal housing on the opposing side of the dash panel. The booster pushrod is secured to pedal arm using a clevis pin and clip arrangement. The two (2) housings together enclose all of the booster components.

Figure D-53: Base Brake Booster with Master Cylinder

D.5.1.2.2 Vacuum Booster (HEV Fusion)

A dual diaphragm active booster (**Figure D-54**) is utilized on the Fusion hybrid. The booster, in like manner to the base Fusion, uses a vacuum supply, master cylinder mounting, and pedal attachment features. The dual diaphragm design is typical of current automotive boosters. The electronic components that are added to the base vehicle brake booster include a position sensor, pressure sensor, and actuation solenoid (Reference **Figure D-55** and **Figure D-56**).

Figure D-54: Dual Diaphragm Booster

The additional components increases sealing requirements for the front cover since they pass through their own individual ports. A position sensor provides feedback on stroke/travel of the diaphragm. It is pressed into the front cover and retained with a plastic adapter. This sensor is spring loaded and requires no direct attachment to the diaphragm. A pressure sensor used to determine if the vacuum pump needs to be run during engine off modes is also pressed in place with a snap fit.

Figure D-55: Diaphragm Position & Pressure Sensor

The solenoid is added to actuate the input rod to the master cylinder, and requires an extra jumper harness. It provides connection from inside the booster to the engine harness through the cover. The solenoid is set directly over the input shaft to the master cylinder and integrated into the center valve design of a typical conventional booster.

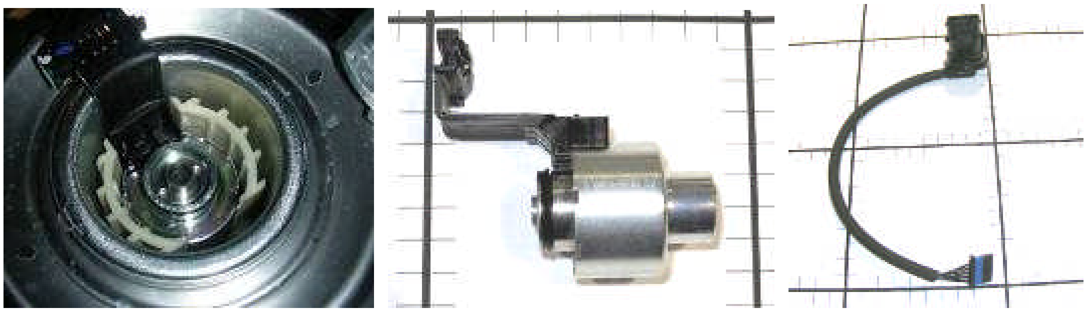


Figure D-56: Actuator Solenoid and Additional Harness

The last unique feature on the hybrid Fusion's booster is a slotted clevis (**Figure D-57**). The slotted clevis eliminates the traditional mechanical link between the brake pedal arm and booster under normal braking conditions. During certain system failure modes the clevis pin in the brake arm will travel to the bottom of the clevis slot, permitting mechanical actuation of the brake system similar to a conventional brake system.

Figure D-57: Slotted Clevis with Over Molded Slide

D.5.1.2.3 <u>Vacuum Pump and Motor</u>

The Fusion hybrid utilizes an electric vacuum pump **(Figure D-58)** to maintain vacuum pressure while the gasoline engine is not running. The pump allows the vehicle to sustain sufficient vacuum pressure to the brake booster. It is secured to the lower left side of the engine with an aluminum bracket. A sensor on the brake booster indicates whether or not the pump should be activated. Air is drawn into the pump through the end opposite the pump's case. The pump uses a combination of reed valves on each end to build vacuum pressure via a dual chamber, dual piston design. The vacuum pump has a singular outlet which is split into two (2) separate lines running directly to the intake manifold. The majority of the case components are die cast aluminum parts that bolt together.

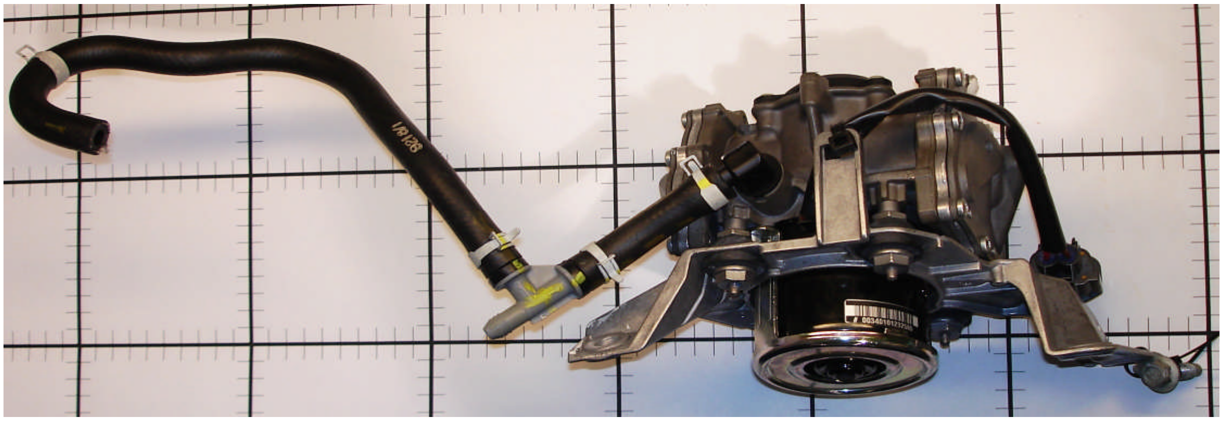


Figure D-58: Vacuum Pump Assembly

D.5.1.3 Brake Control Subsystem

Assessing the additional hardware cost in the existing brake controllers was performed using a fixed cost for each high side and low side driver added to the system. In the Fusion VEV brake system three (3) additional high side drivers were added over the base brake system (i.e., actuator solenoid pedal, actuator solenoid booster, and vacuum pump motor). In addition, four (4) low side drivers were added to the HEV brake system (i.e., pressure sensor pedal, travel sensor pedal, travel sensor booster, and pressure sensor booster).

D.5.2 Brake System Cost Impact

The system overview discussion highlighted the three (3) brake components which saw the greatest magnitude of change required for power-split HEV adaptation. In addition to the three (3) primary components discussed, many secondary/support components were also modified. The cost impact of both the primary and secondary components are captured within their respective subsystems. The three (3) subsystems which contributed to the net incremental, direct manufacturing brake system cost of $236.68 are listed below along with the primary component(s) evaluated within each subsystem. Additional cost details can be found in **Table D-8**.

- Brake Actuation Subsystem ($80.37) (Pedal and Bracket Assembly)
- Power Brake Subsystem ($127.81) (Vacuum Booster Assembly, Vacuum Pump and Motor Assembly)
- Brake Controls Subsystem Power Brake Subsystem ($28.50) (High Side and Low Side Driver Modifications to Control Modules)

Table D-8: Net Incremental Direct Manufacturing Cost of Ford Fusion HEV Brake System in Comparison to Ford Fusion Base Brake System

SYSTEM & SUBSYSTEM DESCRIPTION		NEW TECHNOLOGY GENERAL PART INFORMATION: 2010 Ford Fusion HEV, 2.5L Atkinson Cycle, I4, 156hp (191 Net), (NiMH Battery 275V, Nominal Pack Capacity 5.5Ah, 1.51kWh)										
Item	System/Subsystem Description	Manufacturing			Total Manufacturing Cost (Component/ Assembly)	Markup				Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
		Material	Labor	Burden		End Item Scrap	SG&A	Profit	ED&T-R&D			
	060000 Brake System											
1	06 Brake Actuation Subsystem	$ 43.46	$ 17.00	$ 21.17	$ 81.63	$ 1.02	$ 8.71	$ 7.29	$ 2.19	$ 19.20	$ 0.29	$ 101.12
2	07 Power Brake Subsystem (for Hydraulic)	$ 48.11	$ 33.65	$ 44.27	$ 126.03	$ 0.74	$ 10.29	$ 8.98	$ 3.18	$ 23.19	$ 0.22	$ 149.44
3	09 Brake Controls Subsystem	$ 21.96	$ 0.62	$ 2.10	$ 24.68	$ 0.12	$ 1.60	$ 1.48	$ 0.62	$ 3.82	$ -	$ 28.50
	SYSTEM ROLL-UP	$ 113.54	$ 51.26	$ 67.54	$ 232.34	$ 1.88	$ 20.60	$ 17.75	$ 5.98	$ 46.21	$ 0.51	$ 279.06

SYSTEM & SUBSYSTEM DESCRIPTION		BASE TECHNOLOGY GENERAL PART INFORMATION: 2010 Ford Fusion SE, 3.0L V6, 4-Val. DOHC, NA, PFI, 240hp, 223lb*ft										
Item	System/Subsystem Description	Manufacturing			Total Manufacturing Cost (Component/ Assembly)	Markup				Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
		Material	Labor	Burden		End Item Scrap	SG&A	Profit	ED&T-R&D			
	060000 Brake System											
1	06 Brake Actuation Subsystem	$ 7.13	$ 3.44	$ 7.43	$ 18.01	$ 0.08	$ 1.11	$ 1.06	$ 0.40	$ 2.64	$ 0.10	$ 20.75
2	07 Power Brake Subsystem (for Hydraulic)	$ 6.95	$ 6.47	$ 5.07	$ 18.49	$ 0.10	$ 1.34	$ 1.21	$ 0.47	$ 3.12	$ 0.02	$ 21.63
3	09 Brake Controls Subsystem	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	SYSTEM ROLL-UP	$ 14.08	$ 9.91	$ 12.51	$ 36.50	$ 0.18	$ 2.45	$ 2.27	$ 0.87	$ 5.76	$ 0.12	$ 42.39

SYSTEM & SUBSYSTEM DESCRIPTION		INCREMENTAL COST TO UPGRADE TO NEW TECHNOLOGY PACKAGE										
Item	System/Subsystem Description	Manufacturing			Total Manufacturing Cost (Component/ Assembly)	Markup				Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
		Material	Labor	Burden		End Item Scrap	SG&A	Profit	ED&T-R&D			
	060000 Brake System											
1	06 Brake Actuation Subsystem	$ 36.33	$ 13.56	$ 13.74	$ 63.62	$ 0.94	$ 7.59	$ 6.23	$ 1.79	$ 16.55	$ 0.20	$ 80.37
2	07 Power Brake Subsystem (for Hydraulic)	$ 41.16	$ 27.17	$ 39.20	$ 107.54	$ 0.64	$ 8.95	$ 7.77	$ 2.71	$ 20.07	$ 0.20	$ 127.81
3	09 Brake Controls Subsystem	$ 21.96	$ 0.62	$ 2.10	$ 24.68	$ 0.12	$ 1.60	$ 1.48	$ 0.62	$ 3.82	$ -	$ 28.50
	SYSTEM ROLL-UP	$ 99.45	$ 41.35	$ 55.03	$ 195.83	$ 1.70	$ 18.14	$ 15.48	$ 5.12	$ 40.45	$ 0.40	$ 236.68

D.6 Climate Control System and Cost Summary Overview

D.6.1 Climate Control Hardware Overview

The HEV technology configuration drove both a heating and defrosting, and refrigeration/air conditioning, subsystem change. An auxiliary water pump was added for the heating and defrosting subsystem to maintain hot coolant flow through the heater core during ICE shutdown mode. In the refrigeration/air conditioning subsystem, an electric compressor is required to maintain cool air flow in the passenger compartment during ICE shutdown mode. Beyond the compressor there is little to no difference in plumbing of the refrigerant lines. The condensers and evaporators are found to be the same on both vehicles and are excluded from the analysis.

D.6.1.1 Heating Defrosting Subsystem

The Fusion HEV auxiliary coolant pumping subsystem contains an auxiliary water pump (shown in **Figure D-59**) mounting bracket, electrical jumper harness, and additional coolant lines/hardware required to splice into conventional engine coolant pumping system.

Figure D-59: Auxiliary Water Pump

D.6.1.2 Refrigeration/Air Conditioning Subsystem

D.6.1.2.1 Refrigeration/Air Conditioning Subsystem (Base Fusion)

The belt-driven compressor is a typical piston design (**Figure D-60**) driven by a swash plate. An external electromagnetic clutch is utilized for compressor control. Based on the unique differences between the two (2) systems, the gas AC compressor was completely disassembled and analyzed.

Figure D-60: Belt-Driven Compressor and Mounting Hardware

The conventional compressor consists of a two- (2-) piece main housing, external electromagnetic clutch (drive pulley), two (2) end caps, a shaft with a swash plate, pistons and various stamped plates for flow control (reed valves).

The compressor clutch is applied by an electromagnet integrated into the compressor's drive pulley area (**Figure D-61**). The magnet, when energized, couples the shaft to the drive pulley, which, in turn, actuates the pistons inside the pump. The magnet consists of a copper wound coil setting inside a U channel (stamped steel) with a lower insulator and an external potting compound sealing the unit. The magnet is a stationary part fixed to the front of the compressor. The drive pulley consists of the rotating member, which is driven by the accessory drive belt and rides on a sealed bearing. The inner portion of the pulley is attached to the compressor shaft end via splines.

Figure D-61: Electromagnetic Clutch and Pulley with Bearing

The compressor shaft has a swash plate pressed onto the middle of the shaft (**Figure D-62**). This plate converts the rotating motion to reciprocating motion, which drives the pistons up and down in their respective bores. The pistons are a dual piston design with chambers within both main housings. They are machined cast aluminum with polytetrafluoroethylene sealing rings on each end. The shaft has numerous machined surfaces including ground and splined features for component interfaces.

Figure D-62: Pistons, Cylinder Bore and Swash Plate

A series of stamped coated plates are used on each end of the pump, making up the reed valves and sealing the system (**Figure D-63**).

Figure D-63: Sealing Plate and Reed Valves

The two (2) main housings and both end caps (**Figure D-64**) are die cast aluminum designs. The main housings (**Figure D-65**) both contain bores for the pistons and cross flowing internal ports connecting both ends of the compressor. The shaft bearings are also pressed into each of the main housings. The front end cap provides shaft sealing while the rear cover contains a pressure relief valve. The entire assembly is secured with five (5) long bolts that are inserted from the front through both housings and threads into the rear end cap.

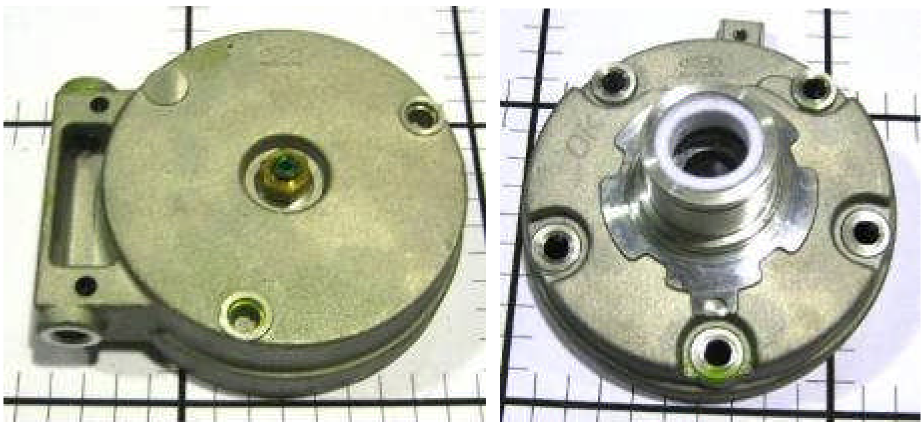


Figure D-64: AC Compressor End Caps

Figure D-65: AC Compressor Main Housings with Center Bores

D.6.1.2.2 <u>Refrigeration / Air Conditioning Subsystem (HEV Fusion)</u>

The electric compressor, including electronic controls, is completely self-contained (**Figure D-66**). The compressor is a scroll design, unlike the gas piston version. Although it could have been located virtually anywhere between the evaporator and condenser, it is attached directly to the engine in the same location. The compressor receives power from the High Voltage Low Current (HVLC) cables coming from the Bussed Electrical Distribution Center (BEC).

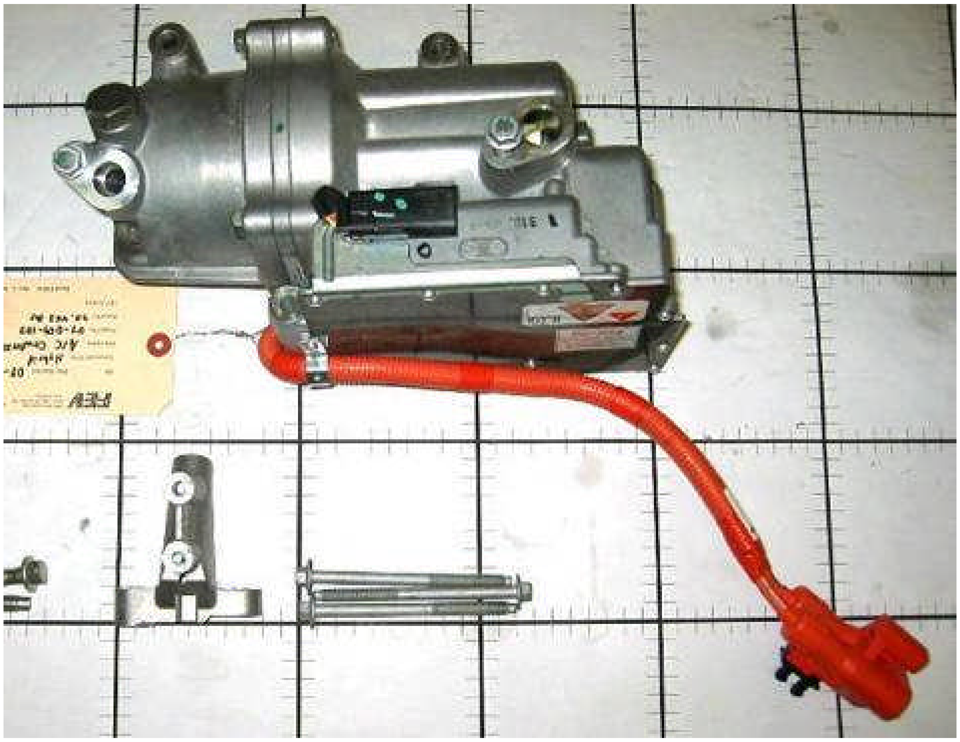


Figure D-66: Electric Compressor and Mounting Hardware

The compressor assembly consists of a main housing, end cap (scroll housing), scroll, electronic controls, and a short harness assembly. The main housing is a machined die cast aluminum part. One end has a bore for the electric motor and scroll mounting. The top of the housing contains a stepped pocket (cavity) for the electronics (**Figure D-67**). Two (2) of the three (3) mounting bosses are cast into the housing.

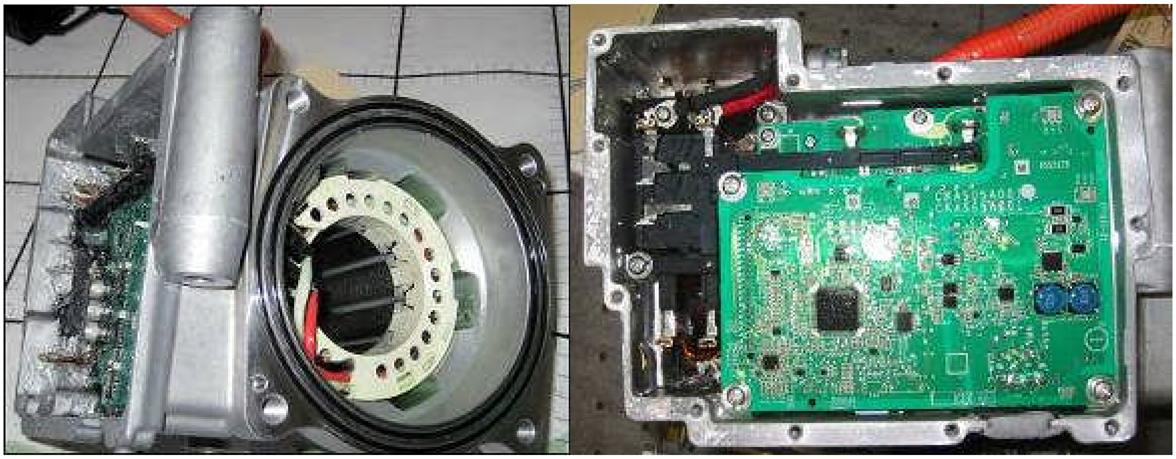


Figure D-67: Main Housing and Electronics

The main housing electrical cavity which houses all of the electronic components is filled with potting compound. Two (2) Printed Circuit Boards (PCBs) and a separate IGBT mount plate (heat sink) are located inside the housing along with various coils, terminal blocks, and a capacitor (**Figure D-68**). Components are attached to the PCBs via a combination of processes which includes surface mount (fully automated), thru hole (both automated and manual) and threaded fasteners. All circuits passing through the housing are sealed. The PCBs and cavity are fully potted and covered with a stamped steel plate.

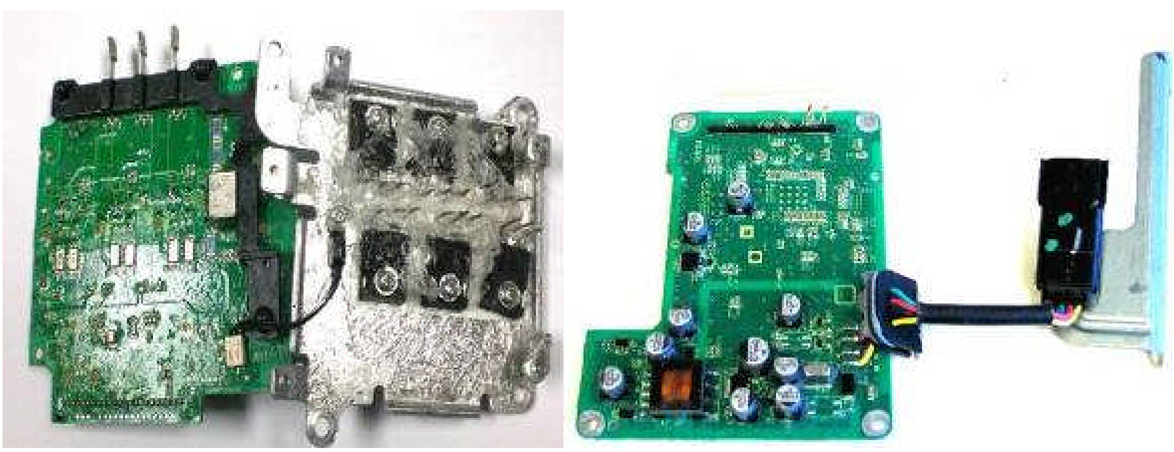


Figure D-68: Printed Circuit Boards (PCBs) and IGBT Heatsink Plate

A High Voltage Low Current (HVLC) pigtail (**Figure D-69**) is attached to the compressor and connected to the High Voltage (HV) harness in the engine compartment. As with the main harness, the pigtail contains EMI shielding and safety interlocks for power disconnect during service.

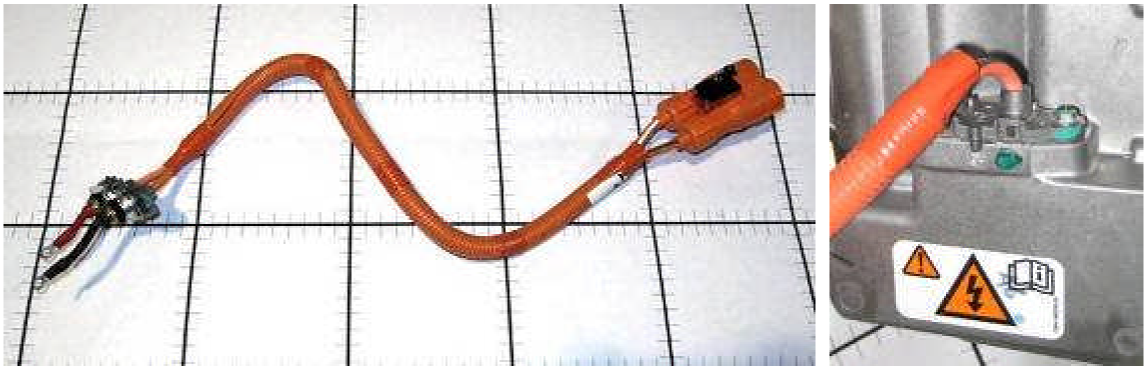


Figure D-69: High Voltage Low Current (HVLC) AC Compressor Pigtail

The electric motor's stator and rotor (**Figure D-70**) are contained inside the main housing. The stator sits inside the main housing (**Figure D-71**), while the rotor is preassembled to a shaft and intermediate plate. The rotor also has a set of counter weights: one (1) on each end of the steel plate stack.

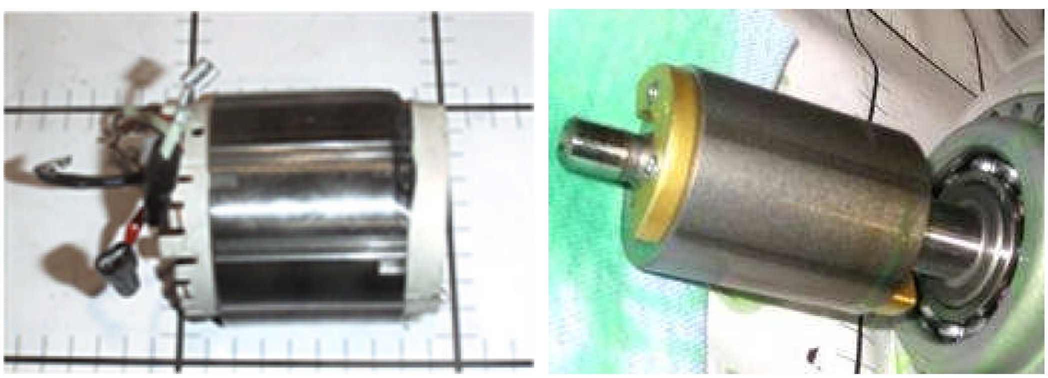


Figure D-70: Stator and Rotor on Bench

Figure D-71: Stator and Rotor in Assembly

The rotor shaft is mounted to an intermediate plate that provides the oscillating motion for the scroll by utilizing an eccentric drive design on the end of the shaft (**Figure D-72**). The scroll housing captures the intermediate plate to the main housing with threaded fasteners.

Figure D-72: Eccentric Drive and Scroll Housing

The scroll housing is a machined aluminum die casting which mounts to the end of the AC compressor (**Figure D-73**). This housing contains both inlet and outlet ports for the AC refrigerant. One (1) of the three (3) AC compressor mounting bosses is cast into the scroll housing.

Figure D-73: Scrolls and Scroll Housing with Mounting Boss for AC Compressor

D.6.2 Climate Control Cost Impact

The addition of the auxiliary coolant pump and associated hardware increases the heating defrosting subsystem direct manufacturing cost of the Fusion HEV by $45.91 over the baseline subsystem. The refrigeration/air conditioning subsystem for the Fusion HEV also saw an increase in cost of $167.54 over the base Fusion. The incremental increase was primarily driven by the higher direct manufacturing cost of the electric air conditioning (AC) compressor ($251.30) over the mechanical driven AC compressor ($83.75). The net incremental, direct manufacturing cost of the climate control system for the Fusion HEV over the base Fusion was $213.46; reference **Table D-9** and Section H, Appendix A for additional details.

Table D-9: Net Incremental Direct Manufacturing Cost of Ford Fusion HEV Climate Control System in Comparison to Ford Fusion Base Climate Control System

SYSTEM & SUBSYSTEM DESCRIPTION		NEW TECHNOLOGY GENERAL PART INFORMATION: 2010 Ford Fusion HEV, 2.5L Atkinson Cycle, I4, 156hp (191 Net), (NiMH Battery 275V, Nominal Pack Capacity 5.5Ah, 1.51kWh)										
Item	System/Subsystem Description	Manufacturing: Material	Manufacturing: Labor	Manufacturing: Burden	Total Manufacturing Cost (Component/ Assembly)	Markup: End Item Scrap	Markup: SG&A	Markup: Profit	Markup: ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
	120000 Climate Control											
1	02 Heating Defrosting Subsystem	$ 27.27	$ 5.53	$ 5.27	$ 38.07	$ 0.27	$ 2.89	$ 3.11	$ 1.43	$ 7.69	$ 0.15	$ 45.91
2	03 Refrigeration/Air Conditioning Subsystem	$ 148.86	$ 23.86	$ 43.32	$ 216.04	$ 1.85	$ 14.57	$ 13.38	$ 5.46	$ 35.25	$ -	$ 251.30
	SYSTEM ROLL-UP	$ 176.13	$ 29.38	$ 48.59	$ 254.11	$ 2.12	$ 17.46	$ 16.48	$ 6.89	$ 42.95	$ 0.15	$ 297.21

SYSTEM & SUBSYSTEM DESCRIPTION		BASE TECHNOLOGY GENERAL PART INFORMATION: 2010 Ford Fusion SE, 3.0L V6, 4-Val. DOHC, NA, PFI, 240hp, 223lb*ft										
Item	System/Subsystem Description	Manufacturing: Material	Manufacturing: Labor	Manufacturing: Burden	Total Manufacturing Cost (Component/ Assembly)	Markup: End Item Scrap	Markup: SG&A	Markup: Profit	Markup: ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
	120000 Climate Control											
1	02 Heating Defrosting Subsystem											
2	03 Refrigeration/Air Conditioning Subsystem	$ 24.10	$ 19.18	$ 25.92	$ 69.20	$ 0.58	$ 6.52	$ 5.56	$ 1.89	$ 14.56		$ 83.75
	SYSTEM ROLL-UP	$ 24.10	$ 19.18	$ 25.92	$ 69.20	$ 0.58	$ 6.52	$ 5.56	$ 1.89	$ 14.56	$ -	$ 83.75

SYSTEM & SUBSYSTEM DESCRIPTION		INCREMENTAL COST TO UPGRADE TO NEW TECHNOLOGY PACKAGE										
Item	System/Subsystem Description	Manufacturing: Material	Manufacturing: Labor	Manufacturing: Burden	Total Manufacturing Cost (Component/ Assembly)	Markup: End Item Scrap	Markup: SG&A	Markup: Profit	Markup: ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
	120000 Climate Control											
1	02 Heating Defrosting Subsystem	$ 27.27	$ 5.53	$ 5.27	$ 38.07	$ 0.27	$ 2.89	$ 3.11	$ 1.43	$ 7.69	$ 0.15	$ 45.91
2	03 Refrigeration/Air Conditioning Subsystem	$ 124.76	$ 4.68	$ 17.40	$ 146.85	$ 1.27	$ 8.04	$ 7.82	$ 3.57	$ 20.70	$ -	$ 167.54
	SYSTEM ROLL-UP	$ 152.04	$ 10.21	$ 22.67	$ 184.91	$ 1.53	$ 10.94	$ 10.93	$ 5.00	$ 28.39	$ 0.15	$ 213.46

D.7 Electrical Power Supply System and Cost Summary Overview

D.7.1 Electrical Power Supply Hardware Overview

The power-split HEV technology created four (4) major subsystem changes within the electrical power supply system: The Service battery subsystem yielded a small savings in favor of the Fusion HEV due to the downsized conventional service battery. The Generator/Alternator and Regulatory Subsystem also yielded a savings for the Fusion HEV since the conventional alternator assembly was no longer required for the HEV power-split configuration. There was a large direct manufacturing cost impact to the High Voltage Traction Battery Subsystem due to the addition of a 275 volt, 5.5 Ampere-Hour (Ah) Nickel Metal Hydride battery, supporting control modules, and miscellaneous hardware. Lastly the Voltage Converter/Inverter Subsystem for the HEV received a cost penalty due to the addition of the DC-DC converter which replaced the conventional alternator.

D.7.1.1 High Voltage Traction Battery Subsystem

The High Voltage Traction Battery is comprised of twenty-six (26) sub-modules connected in series (**Figure D-74**). Each sub-module contains eight (8) Nickel Metal Hydride (NiMH) D-cells connected in series (**Figure D-75**). The battery packs have molded features to facilitate mounting, promote airflow, and fixture temperature sensors. The resulting two hundred eight (208) cells as wired produce 275 volts with a capacity of 5.5 Ah.

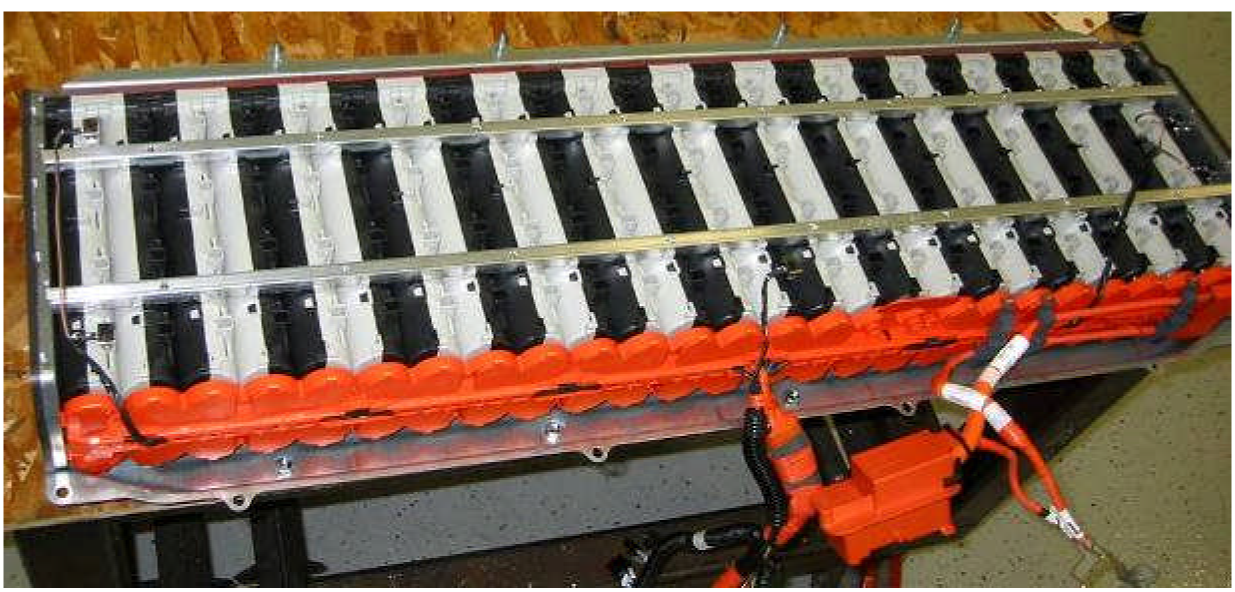


Figure D-74: NiMH Battery Packs Wired in Series

Figure D-75: NiMH Battery Sub-Modules Contain Eight (8) D-Cells Assemble in Series

The D-Cell construction at the most basic level consists of a stamped can, into which an anode collector and rolled electrode assembly are inserted. A cathode collector and vented top are then fitted to the can with a seal. The can is finished with a rolled metal edge which seals and secures the top to the can. **Figure D-76** shows some of the basic components used to produce a D-cell battery.

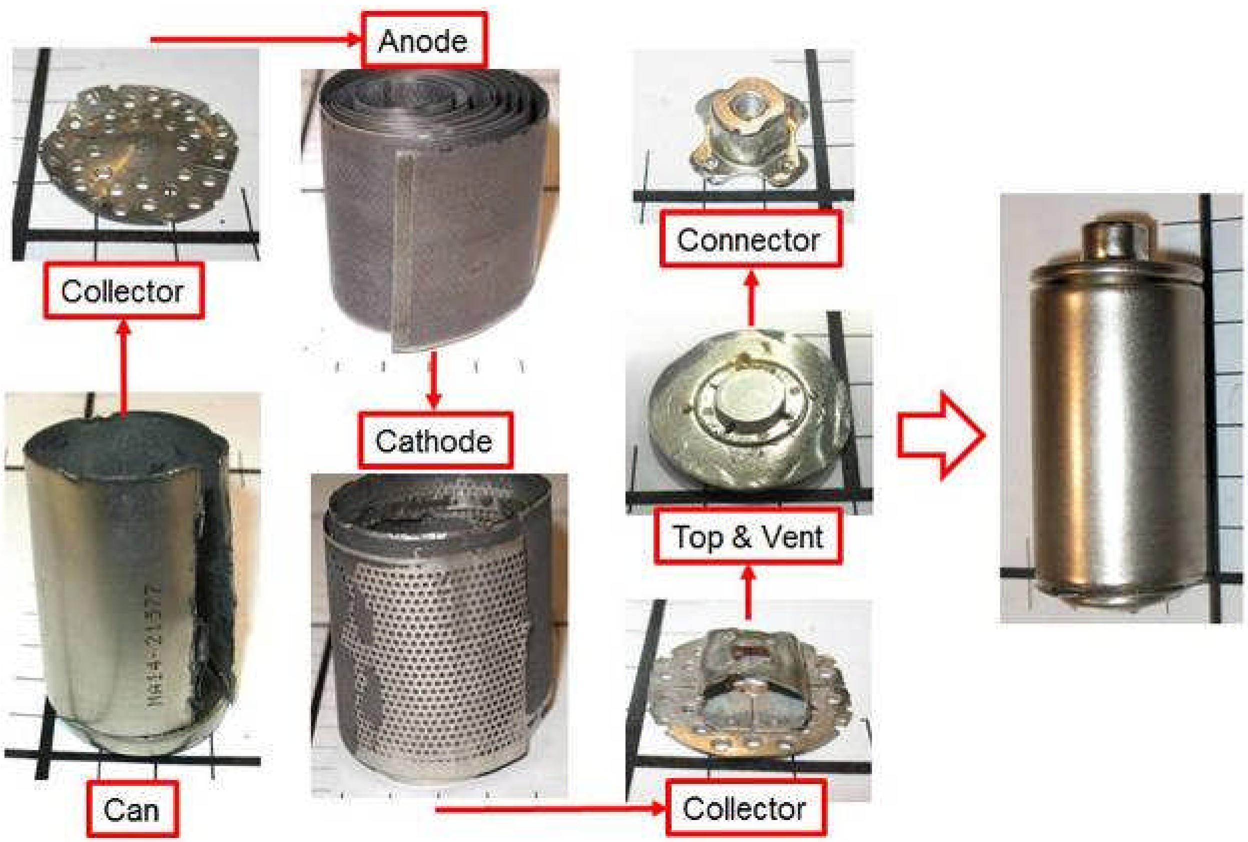


Figure D-76: NiMH Cell Construction

Circuit connections between packs are small buss bars in a molded carrier for insulation (**Figure D-77**). Voltage sensors are integrated into the connection assembly. Temperature sensors are placed strategically at five (5) places in the traction battery assembly.

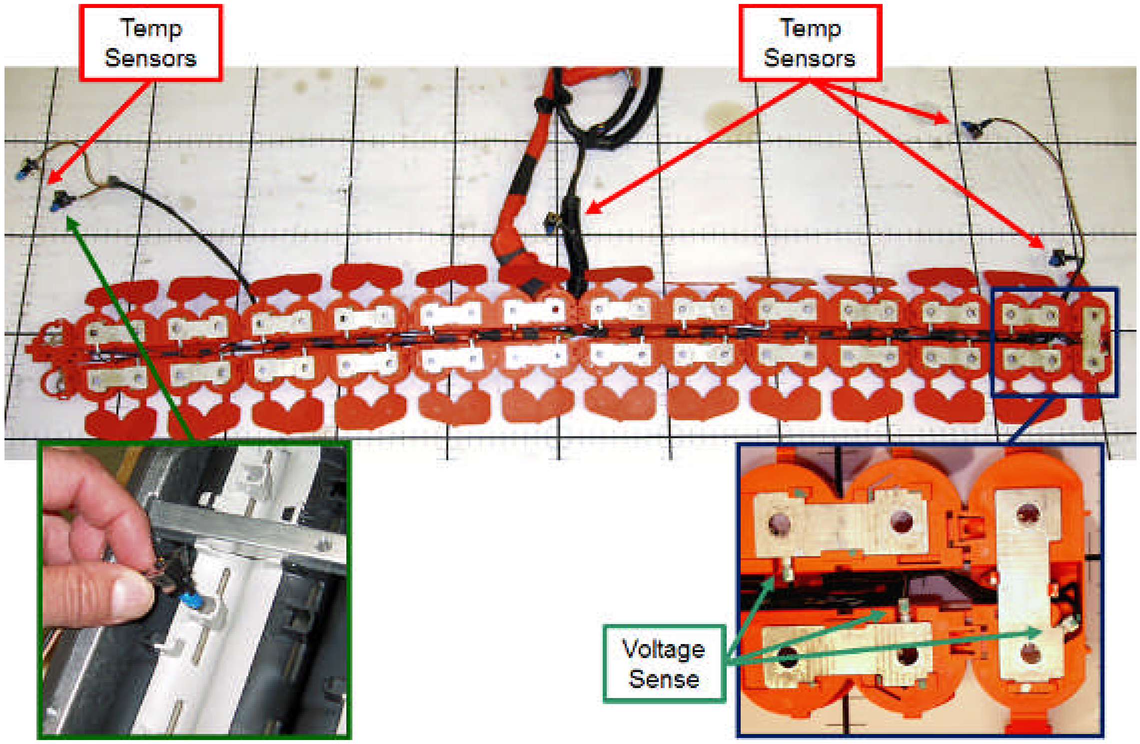


Figure D-77: Battery Connections and Sensors

Stamped steel covers (**Figure D-78** and **Figure D-79**) are employed to closeout and direct air flow over the batteries. A cooling plenum (**Figure D-80**) and speed regulated fan (**Figure D-81**) are mounted to the rear of the traction battery assembly. The fan pulls air through the battery housing from under the rear seat bottom in the cabin.

Figure D-78: Stamped Battery Cover (Under plenum, luggage compartment side)

Figure D-79: Stamped Battery Cover (Cabin side)

Figure D-80: Battery Plenum and Cooling Fan (Top rear view)

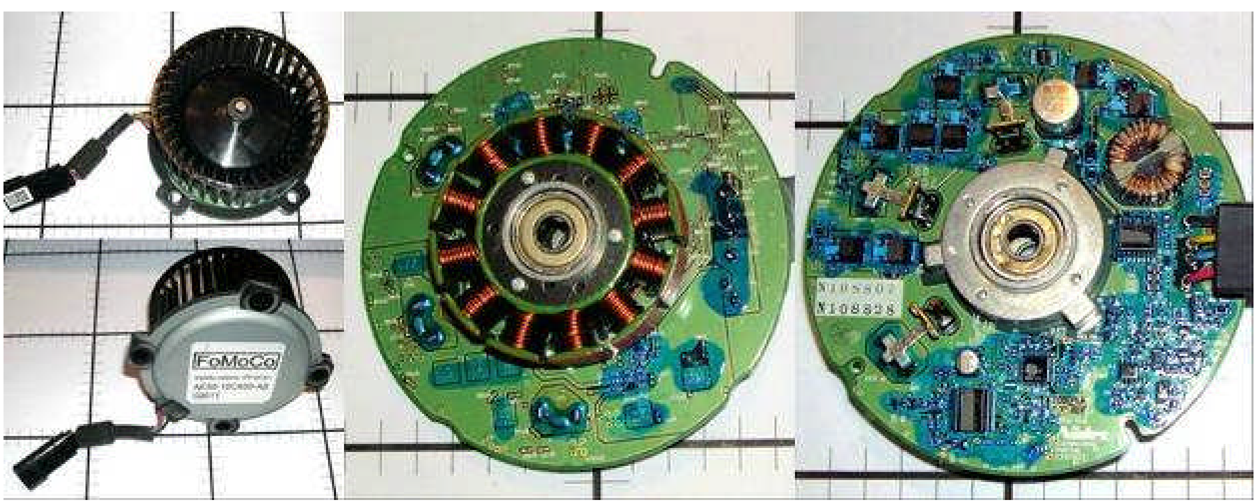


Figure D-81: Electronically Regulated Fan

The traction battery assembly is mounted behind the rear seat back panel. A Bussed Electrical Center (BEC), Battery Disconnect, Battery Pack Sensor Module (BPSM), and Battery Energy Control Module (BECM) are mounted on the cabin side of the traction battery above the cooling air inlet (**Figure D-82**).

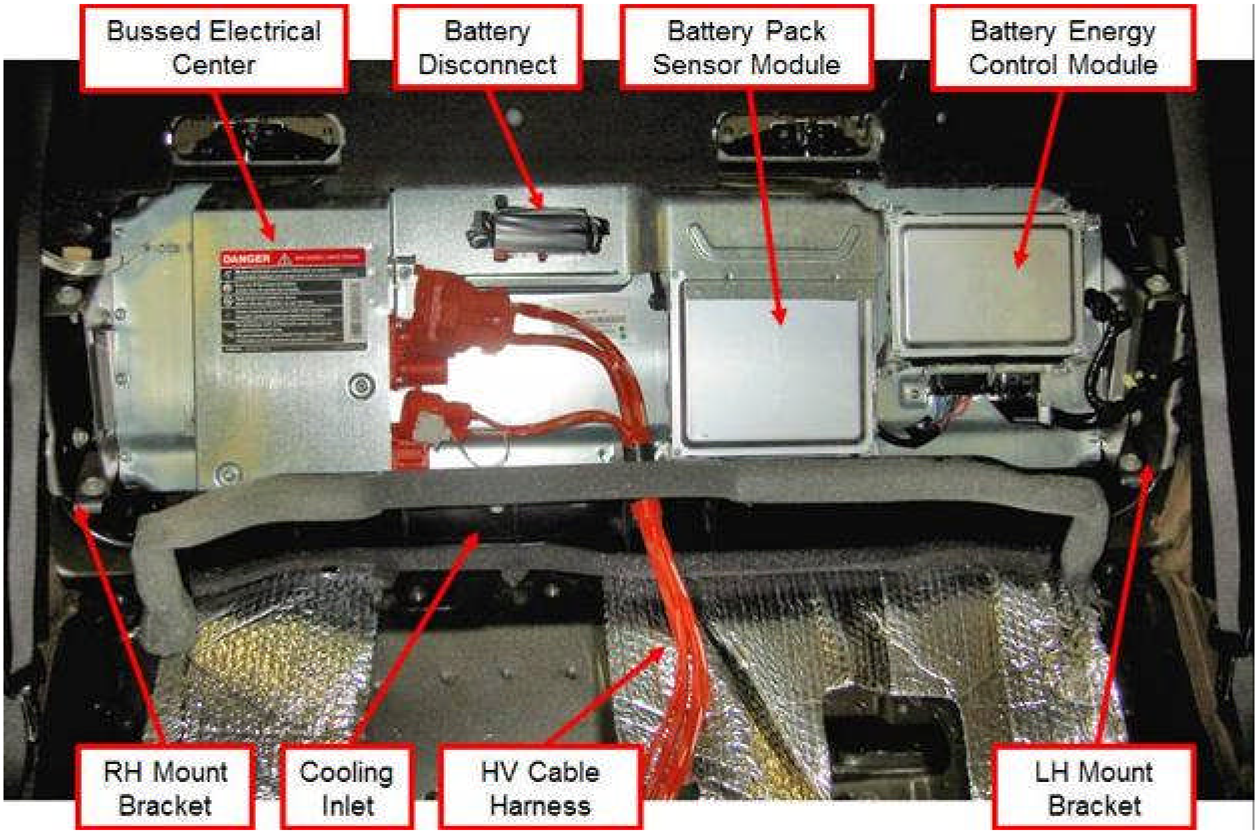


Figure D-82: Battery Assembly Mounted in Vehicle (Cabin side)

The BECM (**Figure D-83**) is responsible for managing both current flow via the Bussed Electrical Center (BEC), and battery health via the Battery Pack Sensor Module (BPSM). The BECM monitors the cooling air inlet temperature and controls the cooling fan for the batteries. High Speed CAN (HS CAN) was employed to communicate with various modules, including the BPSM, Transmission Control Module (TCM), Powertrain Control Module (PCM), and DC-DC Converter Module.

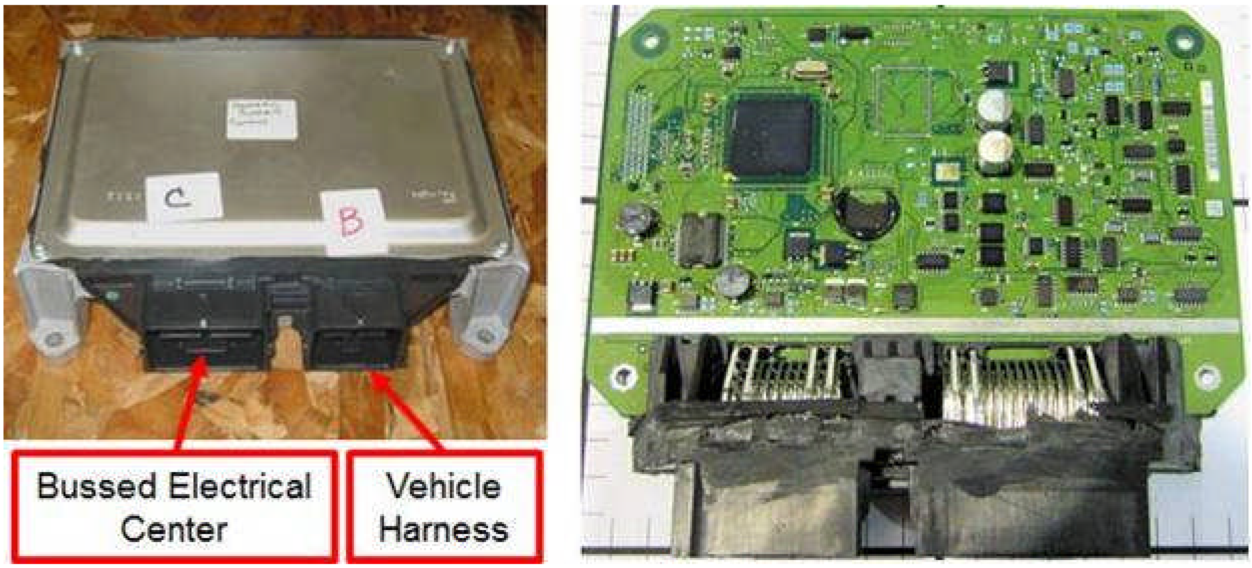


Figure D-83: The Battery Energy Control Module (BECM)

The BPSM (**Figure D-84**), as its name implies, monitors various voltage and temperature sensors on the battery packs. It also monitors the charging system and BEC. Communication with the BECM and other key powertrain modules are via HS CAN.

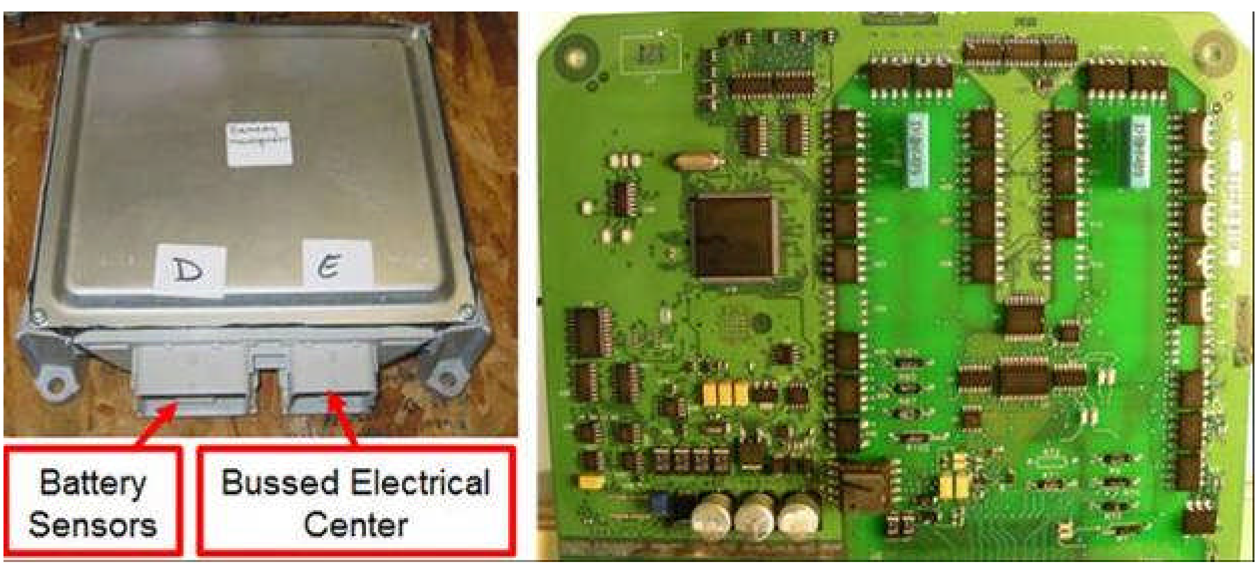


Figure D-84: Battery Pack Sensor Module (BPSM)

During dormant periods the BEC (**Figure D-85**) disconnects the traction battery from the vehicle electrical system. The BEC houses three (3) sophisticated High Voltage (HV) relays and an inductive current monitor. One (1) of two (2) HV connectors present on the BEC is for a high current connection to the eCVT. The second HV connector is for a fused low current supply to the electric air conditioning compressor and DC-DC converter.

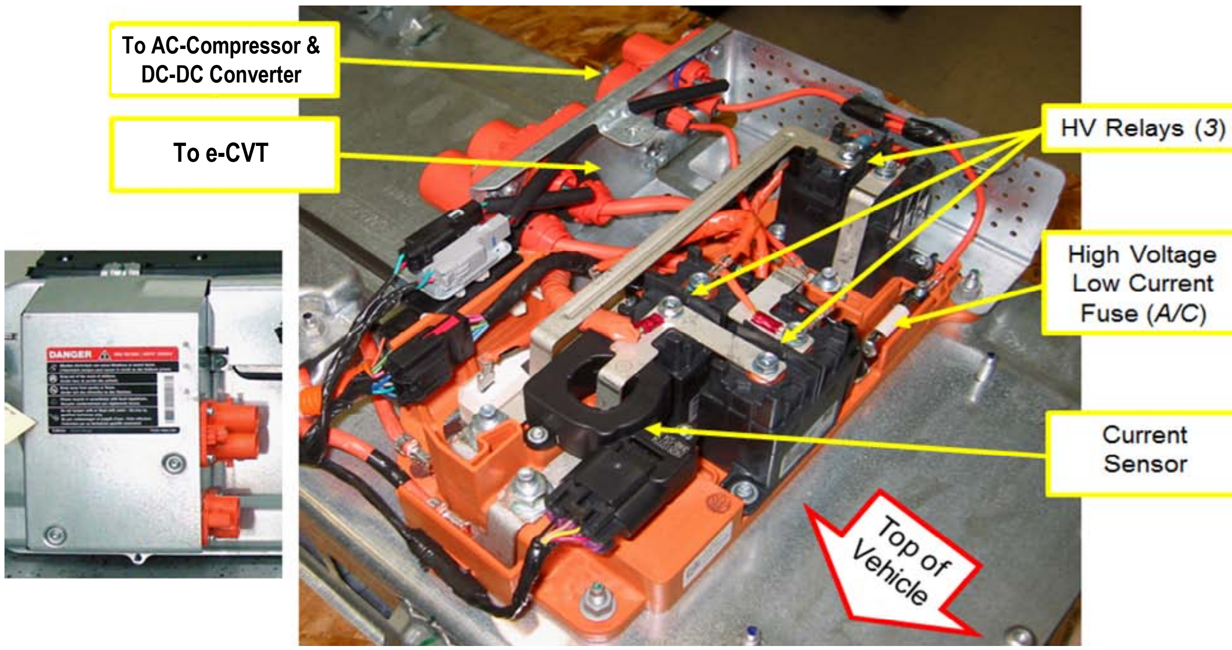


Figure D-85: Bussed Electrical Center (BEC)

D.7.1.2 Voltage Converter/Inverter Subsystem

The DC-DC Converter (**Figure D-86**) is located behind the passenger headlight. It is responsible for converting high voltage to low voltage for the vehicle's standard systems such as power windows, wipers, lighting etc., and charging the 12-volt battery. Connections include 12-volt positive and ground, HV from the BEC, a charging control harness, and coolant lines. HS CAN provides communications with the other vehicle system modules.

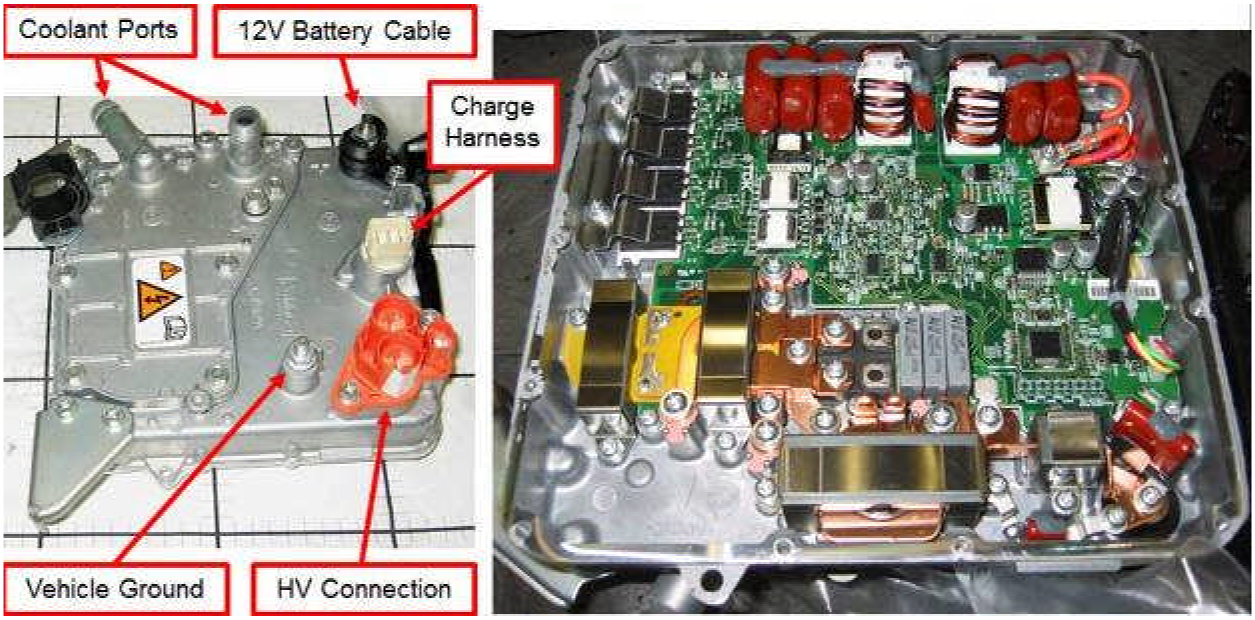


Figure D-86: DC-DC Converter

Due to heat generated during the conversion process, a coolant circuit is required. A sealed coolant passage is integrated into the exterior of the two (2) piece die-cast case (**Figure D-87**). Coolant is circulated through the DC-DC converter module and eCVT via a dedicated cooling system separate from the engine coolant circuit. The interior of the DC-DC converter case functions as a mounting surface and heat sink for the power electronics.

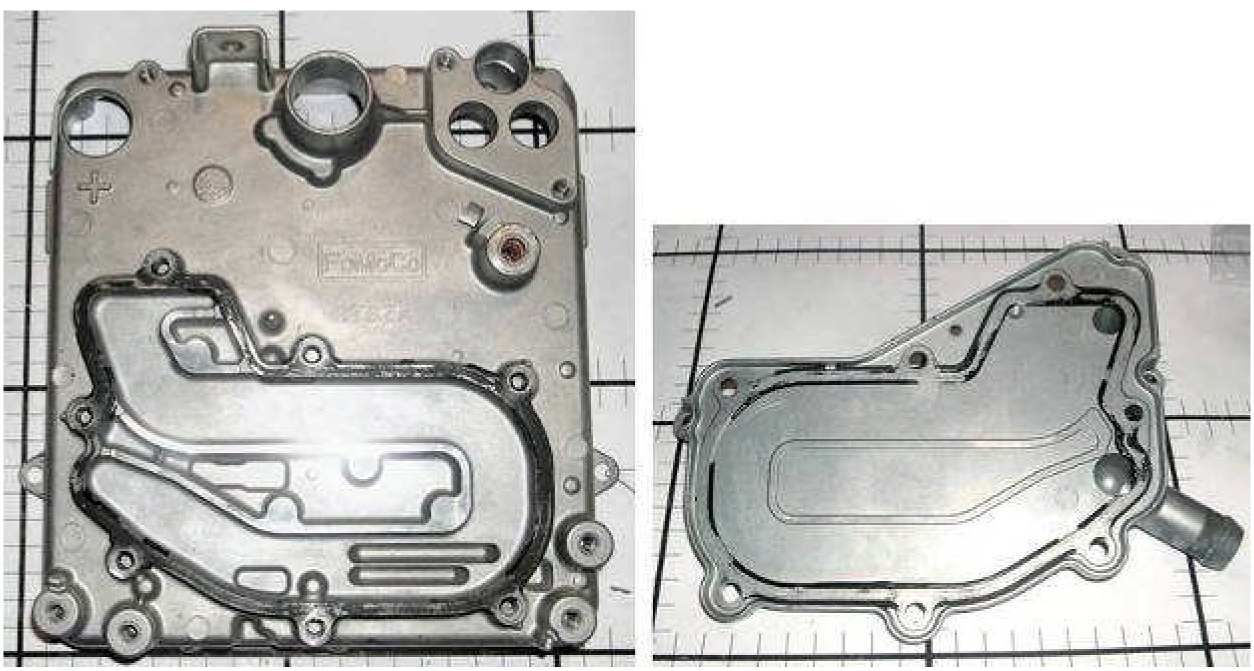
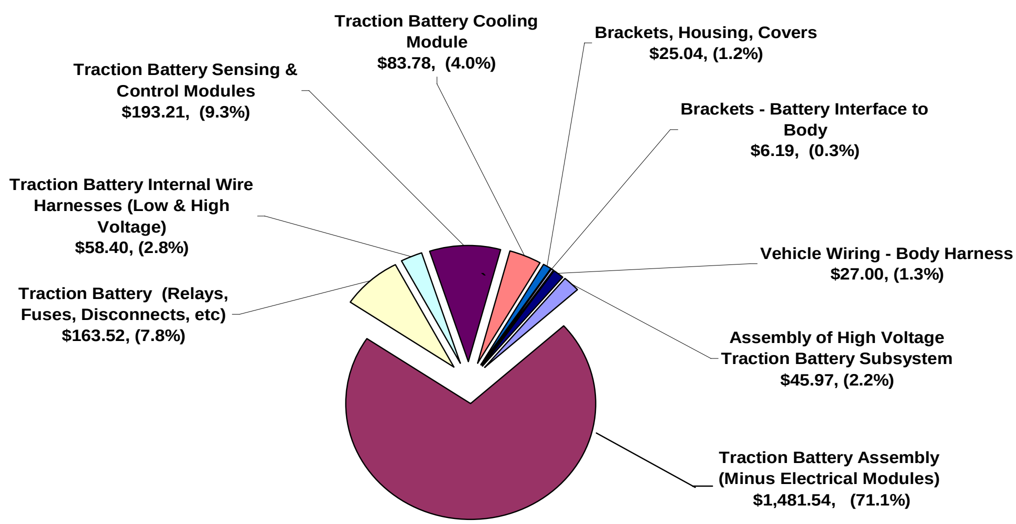


Figure D-87: DC-DC Converter Coolant Passage

D.7.2 Electrical Power Supply Cost Impact

As shown in **Table D-10**, the high voltage traction battery subsystem is by far the largest contributor of cost to the Fusion HEV Electrical Power Supply System – accountable for \$2,084.67 in direct manufacturing costs. This accounts for approximately 61% of the overall direct manufacturing costs of adding power-split hybrid technology to the baseline vehicle. The DC-DC converter adds another \$152.31 to the HEV direct manufacturing costs. However, this cost is partially offset by the deletion of the \$78.70 conventional alternator.

The cost make-up of the NiMH traction battery, broken out by major sub-subsystems and by cost element groups, is shown in **Figure D-88**. The largest cost contributor is the Traction Battery Assembly (71.1%) which includes the cost of the 26 sub-modules and the mounting brackets which secure them together. Additional cost breakdown details for each of these sub-subsystems can be found in **Table D-11** and in Section H, Appendix A.



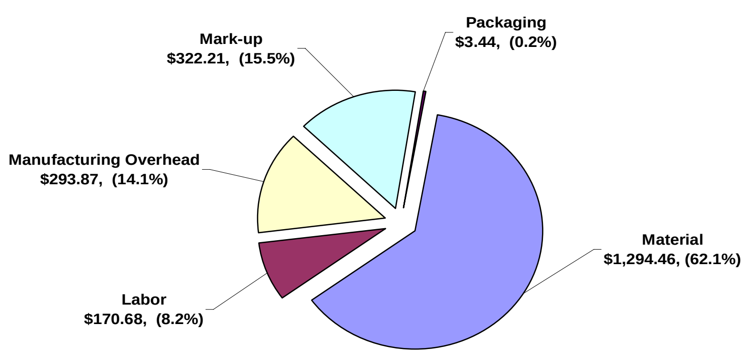


Figure D-88: Ford Fusion 275 Volt, 5.5Ah, NiMH Battery Sub-Subsystem Cost and Major Cost Element Breakdowns

Table D-10: Net Incremental Direct Manufacturing Cost of Ford Fusion HEV Electrical Power Supply System in Comparison to Ford Fusion Base Electrical Power Supply System

SYSTEM & SUBSYSTEM DESCRIPTION — **NEW TECHNOLOGY GENERAL PART INFORMATION: 2010 Ford Fusion HEV, 2.5L Atkinson Cycle, I4, 156hp (191 Net), (NiMH Battery 275V, Nominal Pack Capacity 5.5Ah, 1.51kWh)**

Item	System/Subsystem Description	Manufacturing			Total Manufacturing Cost (Component/ Assembly)	Markup				Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
		Material	Labor	Burden		End Item Scrap	SG&A	Profit	ED&T-R&D			
	140000 Electrical Power Supply System											
1	01 Service Battery Subsystem	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
2	02 Generator/Alternator and Regulator Subsystem	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
3	03 High Voltage Traction Battery Subsystem	$ 1,294.46	$ 170.68	$ 293.87	$ 1,759.01	$ 13.57	$ 119.20	$ 128.32	$ 61.13	$ 322.21	$ 3.44	$ 2,084.65
4	05 Voltage Converter / Inverter Subsystem	$ 89.13	$ 20.84	$ 21.83	$ 131.80	$ 0.66	$ 8.56	$ 7.89	$ 3.27	$ 20.38	$ 0.13	$ 152.31
	SYSTEM ROLL-UP	$ 1,383.60	$ 191.52	$ 315.70	$ 1,890.81	$ 14.22	$ 127.76	$ 136.21	$ 64.40	$ 342.59	$ 3.56	$ 2,236.96

SYSTEM & SUBSYSTEM DESCRIPTION — **BASE TECHNOLOGY GENERAL PART INFORMATION: 2010 Ford Fusion SE, 3.0L V6, 4-Val. DOHC, NA, PFI, 240hp, 223lb*ft**

Item	System/Subsystem Description	Manufacturing			Total Manufacturing Cost (Component/ Assembly)	Markup				Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
		Material	Labor	Burden		End Item Scrap	SG&A	Profit	ED&T-R&D			
	140000 Electrical Power Supply System											
1	01 Service Battery Subsystem	$ 3.00	$ -	$ -	$ 3.00	$ 0.02	$ 0.20	$ 0.18	$ 0.08	$ 0.47	$ -	$ 3.47
2	02 Generator/Alternator and Regulator Subsystem	$ 29.50	$ 11.05	$ 27.95	$ 68.50	$ 0.33	$ 4.23	$ 3.90	$ 1.63	$ 10.08	$ 0.13	$ 78.70
3	03 High Voltage Traction Battery Subsystem	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
4	05 Voltage Converter / Inverter Subsystem	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	SYSTEM ROLL-UP	$ 32.50	$ 11.05	$ 27.95	$ 71.50	$ 0.34	$ 4.42	$ 4.08	$ 1.70	$ 10.54	$ 0.13	$ 82.17

SYSTEM & SUBSYSTEM DESCRIPTION — **INCREMENTAL COST TO UPGRADE TO NEW TECHNOLOGY PACKAGE**

Item	System/Subsystem Description	Manufacturing			Total Manufacturing Cost (Component/ Assembly)	Markup				Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
		Material	Labor	Burden		End Item Scrap	SG&A	Profit	ED&T-R&D			
	140000 Electrical Power Supply System											
1	01 Service Battery Subsystem	$ (3.00)	$ -	$ -	$ (3.00)	$ (0.02)	$ (0.20)	$ (0.18)	$ (0.08)	$ (0.47)	$ -	$ (3.47)
2	02 Generator/Alternator and Regulator Subsystem	$ (29.50)	$ (11.05)	$ (27.95)	$ (68.50)	$ (0.33)	$ (4.23)	$ (3.90)	$ (1.63)	$ (10.08)	$ (0.13)	$ (78.70)
3	03 High Voltage Traction Battery Subsystem	$ 1,294.46	$ 170.68	$ 293.87	$ 1,759.01	$ 13.57	$ 119.20	$ 128.32	$ 61.13	$ 322.21	$ 3.44	$ 2,084.65
4	05 Voltage Converter / Inverter Subsystem	$ 89.13	$ 20.84	$ 21.83	$ 131.80	$ 0.66	$ 8.56	$ 7.89	$ 3.27	$ 20.38	$ 0.13	$ 152.31
	SYSTEM ROLL-UP	$ 1,351.10	$ 180.47	$ 287.75	$ 1,819.31	$ 13.88	$ 123.34	$ 132.13	$ 62.70	$ 332.05	$ 3.44	$ 2,154.80

Table D-11: Net Incremental Direct Manufacturing Cost of Ford Fusion HEV NiMH Battery

SYSTEM & SUBSYSTEM DESCRIPTION		NEW TECHNOLOGY GENERAL PART INFORMATION: 2010 Ford Fusion HEV, 2.5L Atkinson Cycle, I4, 156hp (191 Net), (NiMH Battery 275V, Nominal Pack Capacity 5.5Ah, 1.51kWh)										
		Manufacturing			Total Manufacturing Cost (Component/ Assembly)	Markup				Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
Item	System/Subsystem Description	Material	Labor	Burden		End Item Scrap	SG&A	Profit	ED&T-R&D			
	140300 High Voltage Traction Battery Subsystem											
1	00 Assembly of High Voltage Traction Battery Subsystem	$ 9.18	$ 27.42	$ 9.32	$ 45.92	$ 0.00	$ 0.03	$ 0.02	$ -	$ 0.05	$ -	$ 45.97
2	01 Traction Battery Assembly (Minus Electrical Modules)	$ 921.59	$ 80.45	$ 230.86	$ 1,232.90	$ 11.19	$ 87.68	$ 99.69	$ 49.49	$ 248.05	$ 0.58	$ 1,481.54
3	02 Traction Battery (Relays, Fuses, Disconnects, etc)	$ 117.75	$ 13.84	$ 9.61	$ 141.20	$ 0.71	$ 9.18	$ 8.48	$ 3.53	$ 21.90	$ 0.42	$ 163.52
4	03 Traction Battery Internal Wire Harnesses (Low & High Voltage)	$ 21.96	$ 18.58	$ 9.65	$ 50.19	$ 0.25	$ 3.36	$ 3.06	$ 1.25	$ 7.92	$ 0.29	$ 58.40
5	04 Traction Battery Sensing & Control Modules	$ 150.24	$ 4.03	$ 12.57	$ 166.84	$ 0.83	$ 10.84	$ 10.01	$ 4.17	$ 25.86	$ 0.51	$ 193.21
6	05 Traction Battery Cooling Module	$ 45.82	$ 12.59	$ 13.42	$ 71.83	$ 0.36	$ 4.67	$ 4.31	$ 1.80	$ 11.13	$ 0.81	$ 83.78
7	75 Brackets, Housing, Covers	$ 12.68	$ 5.40	$ 3.73	$ 21.81	$ 0.07	$ 1.35	$ 0.90	$ 0.22	$ 2.53	$ 0.70	$ 25.04
8	96 Brackets - Battery Interface to Body	$ 3.55	$ 0.19	$ 1.19	$ 4.93	$ 0.03	$ 0.57	$ 0.44	$ 0.09	$ 1.13	$ 0.12	$ 6.19
9	97 Vehicle Wiring - Body Harness	$ 11.69	$ 8.18	$ 3.51	$ 23.38	$ 0.12	$ 1.52	$ 1.40	$ 0.58	$ 3.62	$ -	$ 27.00
10												
11												
12												
13												
14												
	SUBSYSTEM ROLL-UP	$ 1,294.46	$ 170.68	$ 293.87	$ 1,759.01	$ 13.57	$ 119.20	$ 128.32	$ 61.13	$ 322.21	$ 3.44	$ 2,084.65

D.8 Electrical Distribution and Electronic Control System and Cost Summary

D.8.1 Electrical Distribution and Electronic Control Hardware Overview

A special high voltage (HV) harness (**Figure D-89:**) is required to handle current flow between the bussed electrical center (BEC) in the high voltage traction battery and the eCVT, DC-DC converter and AC compressor. The main circuits in the HV harness are the high voltage high current (HVHC), high voltage low current (HVLC) and high voltage inter-lock (HVI). The HVHC carries the current primarily for traction, generation, and storage. The HVLC is dedicated to the DC-DC converter and electric AC compressor. HVI is a series serial data circuit that is interrupted when an HV connector is loose. HV system shutdown will occur when an HVI event is detected. Three (3) distinct gauges and lengths of wire cable are used in the construction of the HV harness (**Figure D-90**).

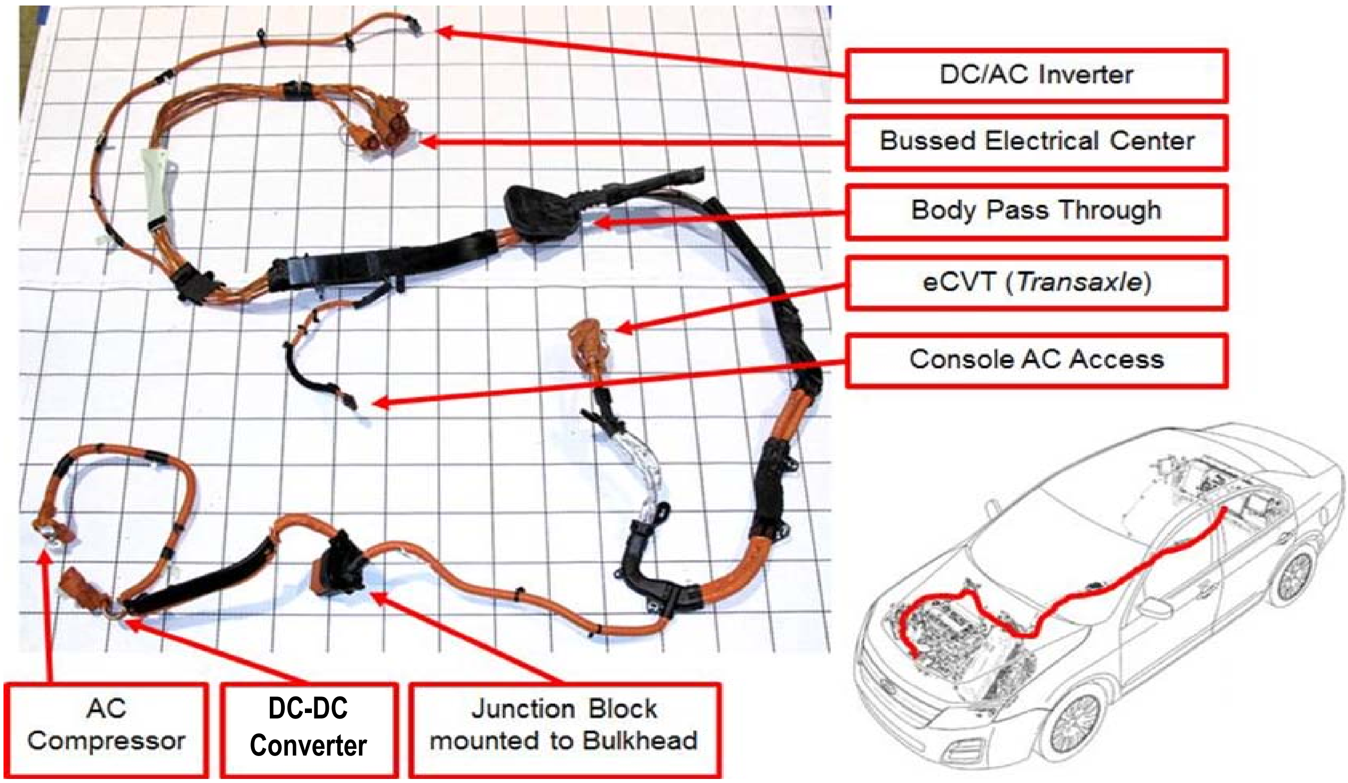


Figure D-89: High Voltage Electrical Harness Connections

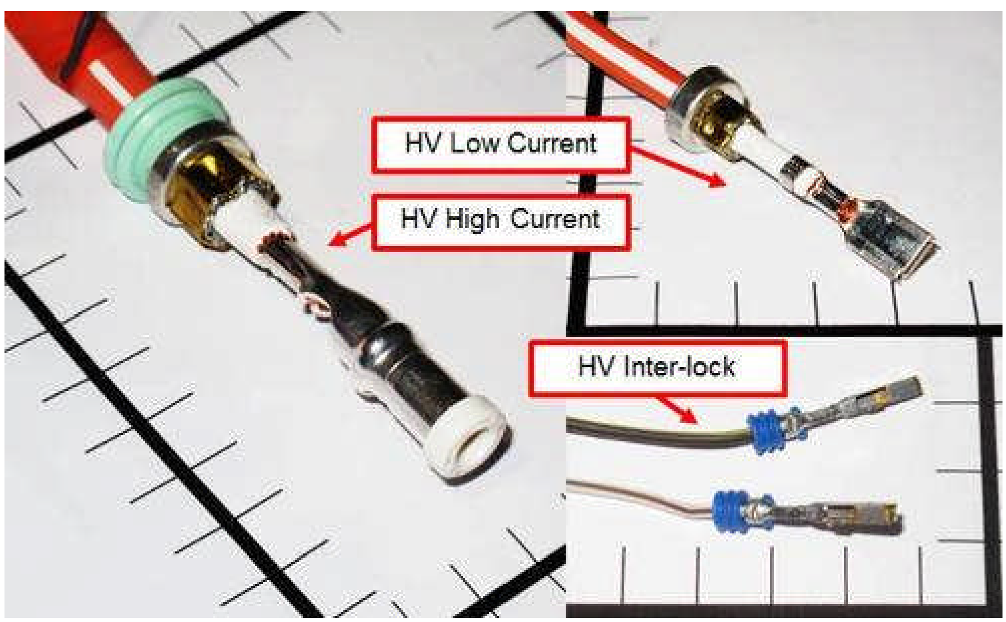


Figure D-90: High Voltage Harness Connections

The HV connectors (**Figure D-91**) are all shielded to protect the vehicle systems from electro-magnetic interference (EMI) and radio frequency interference (RFI). In addition to shielding, the connectors are completely sealed to protect against water ingress.

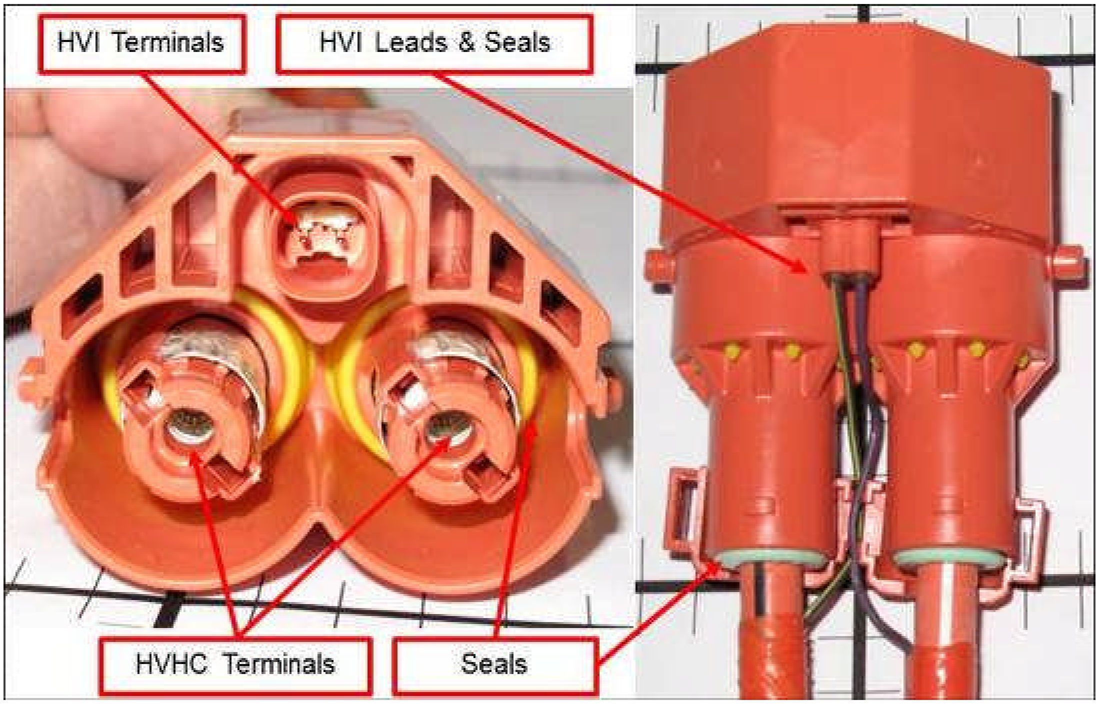


Figure D-91: High Voltage Electrical Connector

The HV disconnect (**Figure D-92**) is a manual plug that interrupts the traction battery current path. It is useful for service personnel and emergency rescue teams when an HV system power down is required. A one hundred (100) amp fuse is housed inside the HV disconnect.

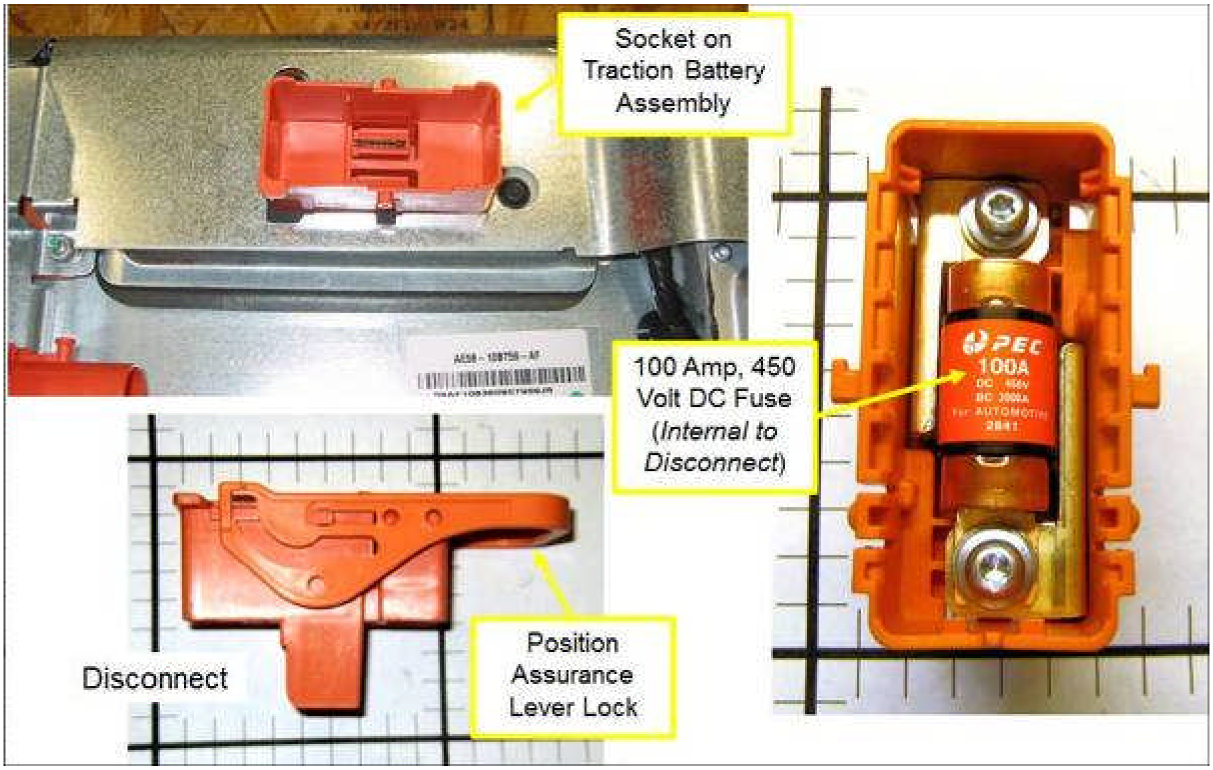


Figure D-92: Battery Disconnect and Main Fuse

D.8.2 Electrical Distribution and Electronic Control Cost Impact

The electrical distribution and electronic control system contains both low and high voltage wiring and controls subsystems for the entire vehicle. For this analysis, when new HEV devices were added to the vehicle, which drove the need for additional wiring and/or controls, the cost of the wiring and/or controls was captured in the added device subsystem or system as opposed to grouping together in a wiring and controls system. The same methodology held true for the deletion of conventional devices.

Therefore, the only direct manufacturing costs captured in the electrical distribution and electronic controls system are for the high voltage wire harness found in the Traction and High Voltage Power Distribution Subsystem. As shown in **Table D-12**, the net incremental, direct manufacturing cost impact of the adding the high voltage wire harness is $201.50. Additional details on the high voltage wire harness can be found in Section H, Appendix A.

Table D-12: Net Incremental Direct Manufacturing Cost of Ford Fusion HEV Electrical Distribution and Electronic Control System in Comparison to Ford Fusion Base Electrical Distribution and Electronic Control System

SYSTEM & SUBSYSTEM DESCRIPTION		NEW TECHNOLOGY GENERAL PART INFORMATION: 2010 Ford Fusion HEV, 2.5L Atkinson Cycle, I4, 156hp (191 Net), (NiMH Battery 275V, Nominal Pack Capacity 5.5Ah, 1.51kWh)										
Item	System/Subsystem Description	Manufacturing: Material	Manufacturing: Labor	Manufacturing: Burden	Total Manufacturing Cost (Component/ Assembly)	Markup: End Item Scrap	Markup: SG&A	Markup: Profit	Markup: ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
	180000 Electrical Distribution and Electronic Control System											
1	06 Traction And High Voltage Power Distribution Subsystem	$ 127.00	$ 32.43	$ 16.16	$ 175.58	$ 0.81	$ 10.64	$ 9.75	$ 4.03	$ 25.23	$ 0.68	$ 201.50
	SYSTEM ROLL-UP	$ 127.00	$ 32.43	$ 16.16	$ 175.58	$ 0.81	$ 10.64	$ 9.75	$ 4.03	$ 25.23	$ 0.68	$ 201.50

SYSTEM & SUBSYSTEM DESCRIPTION		BASE TECHNOLOGY GENERAL PART INFORMATION: 2010 Ford Fusion SE, 3.0L V6, 4-Val. DOHC, NA, PFI, 240hp, 223lb*ft										
Item	System/Subsystem Description	Manufacturing: Material	Manufacturing: Labor	Manufacturing: Burden	Total Manufacturing Cost (Component/ Assembly)	Markup: End Item Scrap	Markup: SG&A	Markup: Profit	Markup: ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
	180000 Electrical Distribution and Electronic Control System											
1	06 Traction And High Voltage Power Distribution Subsystem	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	SYSTEM ROLL-UP	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -

SYSTEM & SUBSYSTEM DESCRIPTION		INCREMENTAL COST TO UPGRADE TO NEW TECHNOLOGY PACKAGE										
Item	System/Subsystem Description	Manufacturing: Material	Manufacturing: Labor	Manufacturing: Burden	Total Manufacturing Cost (Component/ Assembly)	Markup: End Item Scrap	Markup: SG&A	Markup: Profit	Markup: ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
	180000 Electrical Distribution and Electronic Control System											
1	06 Traction And High Voltage Power Distribution Subsystem	$ 127.00	$ 32.43	$ 16.16	$ 175.58	$ 0.81	$ 10.64	$ 9.75	$ 4.03	$ 25.23	$ 0.68	$ 201.50
	SYSTEM ROLL-UP	$ 127.00	$ 32.43	$ 16.16	$ 175.58	$ 0.81	$ 10.64	$ 9.75	$ 4.03	$ 25.23	$ 0.68	$ 201.50

E. Power-Split Sensitivity Analysis

For this case study, it is useful to understand how sensitive the incremental unit cost impact ($3,435) is to any future changes in the cost of materials, labor, burden, or mark-up. The following scenarios were modeled relative to 2010 dollars: supplier and OEM labor cost -20%; burden cost -20%; material cost +/- 20%; mark-up +/- 20%. Given the clear trends in North American manufacturing, only declines were considered for the labor and burden rates within this sensitivity analysis. The percent change in cost for each of these categories was modeled independently. The results for each scenario are shown in **Table E-1**.

Table E-1: Cost Model Sensitivity Study Results

Model Description	Net Component /Assembly Cost Impact to OEM
Baseline, Case Study #0502	$3,435
20% average decrease in labor rates	$3,340 (-3%)
20% average decrease in burden rates	$3,334 (-3%)
20% average decrease in raw material costs(1)	$2,945 (-14%)
20% average increase in raw material costs(1)	$3,925 (+14%)
20% average decrease in mark-up rates	$3,322 (-3%)
20% average increase in mark-up rates	$3,548 (+3%)

[1] Both raw material and commodity purchased components are grouped together in the above sensitivity analysis.

As discussed in Section D.1.2, approximately 71% of the incremental direct manufacturing costs (i.e., $2,865.06) are material costs, 14% labor costs, and 15% overhead costs. Relative to the net incremental direct manufacturing cost of $3,435, approximately 83.5% are total manufacturing costs (i.e., material, labor, overhead) and the remaining 16.5% is applicable mark-up.

More than 95% of the costs for adding the power-split technology to the baseline configuration originate from the transmission (34%) and electrical power supply (63%) systems.

F. Power-Split Scaling Cost Analysis

F.1 Power-Split Methodology Overview

To determine the net incremental direct manufacturing cost for adding power-split powertrain technology to other vehicle segments, a scaling methodology, utilizing the Ford Fusion cost analysis as the foundation, was employed. The first step in the process involved defining the size of the primary powertrain system components (e.g. internal combustion engine [ICE], traction motor, generator motor, high voltage battery) for the defined vehicle segment. This was accomplished by utilizing ratios developed within the Ford Fusion analysis (i.e., Baseline max power/HEV max power ratio, ICE/traction motor horsepower ratio, battery sizing to traction/generator motor sizing, etc.), and applying them to the new vehicle segment to establish primary HEV base component sizes. More details on component sizing for alternative vehicle segments will be discussed in Section F.2.

Once the primary base components were established, component costs within each subsystem/system were developed using manufacturing cost to component size ratios for both the primary base components (e.g. traction motor, high voltage traction battery) and selected vehicle segment attributes (e.g., vehicle footprint, passenger volume, curb weight). The scaled totals for each system were then added together to create an estimated vehicle cost. Additional details on the power-split scaling methodology are discussed in Section F.3.

For power-split hybrid technology, the team decided the best suited applications, in addition to the mid/large size vehicle classification (i.e., Ford Fusion HEV), were as follows: subcompact passenger vehicles, compact/small size passenger vehicles, and mini van/large size passenger vehicles.

F.2 Power-Split Component Sizing

The first step in sizing key power-split powertrain components, is establishing the baseline powertrain and vehicle attributes for each of the selected vehicle classes. **Table F-1Table F-2:** provides the baseline powertrain and vehicle attributes used in the analysis. The values other than the mid/large size passenger vehicle class, which is the Ford Fusion baseline data, are based on EPA acquired, 2008 sales-weighted average data.

The second step in the sizing segment of the analysis was to establish the ICE, traction motor, generator, and high voltage traction battery size for each of the vehicle classifications. This was accomplished by applying sizing ratios, developed within the Ford Fusion power-split HEV and baseline case study, to components in the other vehicle classes.

Table F-1: Baseline Powertrain and Vehicle Attributes for the Additional Vehicle Classes, Under Evaluation for Adding Power-Split HEV Technology

Vehicle Classification			Baseline Technology Configuration: Internal Combustion Engine (ICE) and Automatic Transmission										
Class	Vehicle Class Description	Passenger Capacity	Engine Config.	Trans. Config.	Curb Weight	ICE Power Max		ICE Torque Max		Wheel Base	Track	Passenger Volume
					"lbs"	"kW"	"hp"	"N*m"	"lb*ft"	"mm"	"mm"	"m^3"
1	Subcompact Passenger Vehicle	Passenger (2-4)	I4	6-Speed AT	2628	95.6	128.11	170.8	126.0	2565.40	1498.60	2.535
2	Compact/Small Size Passenger Vehicle	Passenger (2-5)	I4	6-Speed AT	3118	115.3	154.52	203.4	150.0	2717.80	1549.40	2.693
3	Mid/Large Size Passenger Vehicle (Ford Fusion Cost Analysis)	Passenger (4-6)	V6-3.0L	6-Speed AT	3446	179.0	240.00	302.3	223.0	2727.96	1567.18	2.840
4	Mini Van/Large Size Passenger Vehicle	Passenger (6-8)	V6	6-Speed AT	4087	173.9	233.16	317.2	234.0	2819.40	1600.20	3.618

In **Table F-2:** Ford Fusion ratios were developed and then applied to the other vehicle classes to develop key components sizes:

- Fusion Base Power to Fusion HEV Power (“System Power Reduction”) – 79%
- ICE Power to Total System Power (“ICE System Power Ratio”) – 82%
- Traction Motor to System Power Ratio – 43%
- Generator-Motor to System Power Ratio – 21%

To develop the battery sizes for the other vehicle classes, a common run-time (0.0168 hours), at full power consumption, was assumed (**Table F-2**) In addition, battery pack power capacity was increased by adding additional battery cells (i.e., pack sub-modules) in series maintaining constant amperage for all vehicle classifications.

Multiplying the combined traction motor and generator power for each vehicle class by the common run-time (0.0168 hr), a battery capacity in kilowatt hours was calculated. Dividing the battery capacity values by the constant 5.5Ah, the pack voltage for each vehicle class was determined. Also the percent decrease in pack size and reduction in quantity of D-Cell batteries was calculated (**Table F-2**).

Vehicle attributes, such as wheel base, track, and interior passenger volumes, are assumed constant between the baseline vehicle and corresponding power-split HEV replacement configurations. For the scaling analysis, vehicle attributes are utilized in reference to the Mid/Large Size Passenger Vehicle class (i.e., Ford Fusion cost analysis) where component costs and sizes, in relationship to vehicle attributes, have already been established.

For example, a ground-up cost for the Ford Fusion HEV electric air-conditioning (AC) compressor was established at $251.30. To estimate the cost of a subcompact size vehicle electrical AC compressor, a general scaling factor of 0.89 was applied to components within the AC compressor, which could be reduced in size as a result of the smaller cooling volume. The 0.89 scaling factor was developed by dividing the interior passenger volume of the subcompact passenger vehicle (2.535 m^3) by the Ford Fusion interior passenger volume (2.840 m^3).

In the case of the electrical AC compressor, all components within the AC compressor were reduced by the 0.89 scaling factor, other than the two (2) circuit boards, miscellaneous high voltage, passive electronic components, and the high voltage wire pigtail (total value: $130.58). Because many of these electronic-related components would remain the same in a smaller compressor, requiring similar function and performance, or would not change for cross-platform commonality advantages, the scaling factor was not applied.

The estimated value of the subcompact passenger vehicle, electrical AC-compressor, was $238.02 [$238.02 = ($251.30-$130.58)*0.89+$130.58].

Table F-2: Primary Component Sizing for a Range of Power-Split Hybrid Electric Vehicles Classes

Vehicle Classification			New Technology Configuration: Power-split HEV, ICE, Electric Motor, Electric Generator, eCVT, and NiMH Battery															
Class	Vehicle Class Description	Passenger Capacity	System Power Max (ICE+E-Motors)		ICE Power Max			Traction Motor Power Max		Generator Motor Power Max		Nominal Pack Voltage	Nominal Pack Amp Hours	Nominal Battery Pack Supply Energy	Operation Time		Battery Pack Size Relative to Baseline	Addition/ Reduction In Battery Cells Required
			"kW"	System Power Reduction	"kW"	Engine Config.	ICE: System Power Ratio	"kW"	Traction Motor: System Power Ratio	"kW"	Generator Motor: System Power Ratio	"V"	"Ah"	kWhr	Hours	Minutes	Percent	Quantity of D-Cell Batteries (Ave. 1.35V)
1	Subcompact Passenger Vehicle	Passenger (2-4)	75.5	0.79	61.7	I3	0.82	32.22	0.43	16.11	0.21	148	5.5	0.81	0.0168	1.0083	0.54	94
2	Compact/Small Size Passenger Vehicle	Passenger (2-5)	91.1	0.79	74.4	I4-DS	0.82	38.87	0.43	19.43	0.21	178	5.5	0.98	0.0168	1.0083	0.65	72
3	Mid/Large Size Passenger Vehicle (Ford Fusion Cost Analysis)	Passenger (4-6)	140.6	0.79	114.8	I4	0.82	60	0.43	30	0.21	275	5.5	1.51	0.0168	1.0083	NA	NA
4	Mini Van/Large Size Passenger Vehicle	Passenger (6-8)	137.4	0.79	112.2	V6-DS	0.82	58.65	0.43	29.32	0.21	269	5.5	1.48	0.0168	1.0083	0.98	5

F.3 System Scaling Overview

In Table A-1, the net incremental direct manufacturing costs to add power-split HEV technology to a range of vehicle segments are presented. The mid- to large-size passenger vehicle costs are represented by the Ford Fusion cost analysis (case study #0502). The incremental costs for the subcompact size, compact-small size, and minivan-large size passenger vehicle segments, are calculated using the scaling methodology discussed in sections F.1 and F.2.

In the power-split scaling analysis, the application of scaling factors range in complexity from system to system. In simpler cases, a scaling factor was applied to the total component cost. In more complex cases, similar to the electrical AC compressor discussed above, the scaling factor was only applied to the relevant components within the assembly, and/or the scaling factor was only applied against selected cost elements (i.e. material, labor, manufacturing overhead).

G. 2010 Hyundai Avante Lithium Polymer Battery Cost Anaylsis

In addition to evaluating the NiMH battery found in the Ford Fusion, a lithium polymer battery packaged in the 2010 Hyundai Avante and sold domestically in South Korea, was also evaluated (**Figure G-1**). The analysis provided a good comparison of the manufacturing costs between the NiMH and lithium polymer battery, as well as some of the physical attributes of the batteries, namely size and weight. In addition the results from the lithium polymer battery analysis were used in the P2 HEV cost analysis. The EPA team felt the lithium polymer, high voltage battery was a better long-term solution (versus the NiMH battery) for P2 HEV applications.

The Ford Fusion NiMH battery is a larger capacity battery (275 V, 5.5Ah, 1.51kWh, 26 modules approximately, 10.6 volts/module) in comparison to the Hyundai Avante lithium polymer battery (180V, 5.3Ah, 0.954kWh, 6 modules, 30 volts/module). Not accounting for the state of charge (SOC) swing differences between the NiMH and lithium polymer batteries, a size and weight comparison was made by scaling the lithium polymer battery pack up to an equivalent NiMH size by adding three (3) additional modules (30 Volts/Module x 9 = 270 Volts). **Table G-1** below provides the comparison results.

Table G-1: NiMH versus Lithium Polymer High Voltage Battery Attribute Comparison

	NiMH High Voltage Traction Battery	Lithium Polymer High Voltage Traction Battery
Cost/kWh	$1,378	$1,270
Percent Weight Difference	Baseline	46% Reduction Over NiMH
Percent Volume Difference	Baseline	20% Reduction Over NiMH

G.1.1.1 Lithium Polymer High Voltage Traction Battery Subsystem Overview

The High Voltage Traction Battery (as delivered) is comprised of six (6) modules connected in series (**Figure G-2**). Each module contains eight (8) lithium ion polymer battery (LIB) pouch-cells that are connected in series (**Figure G-3**). The battery packs have molded features to facilitate assembly, promote airflow, and fixture temperature sensors.

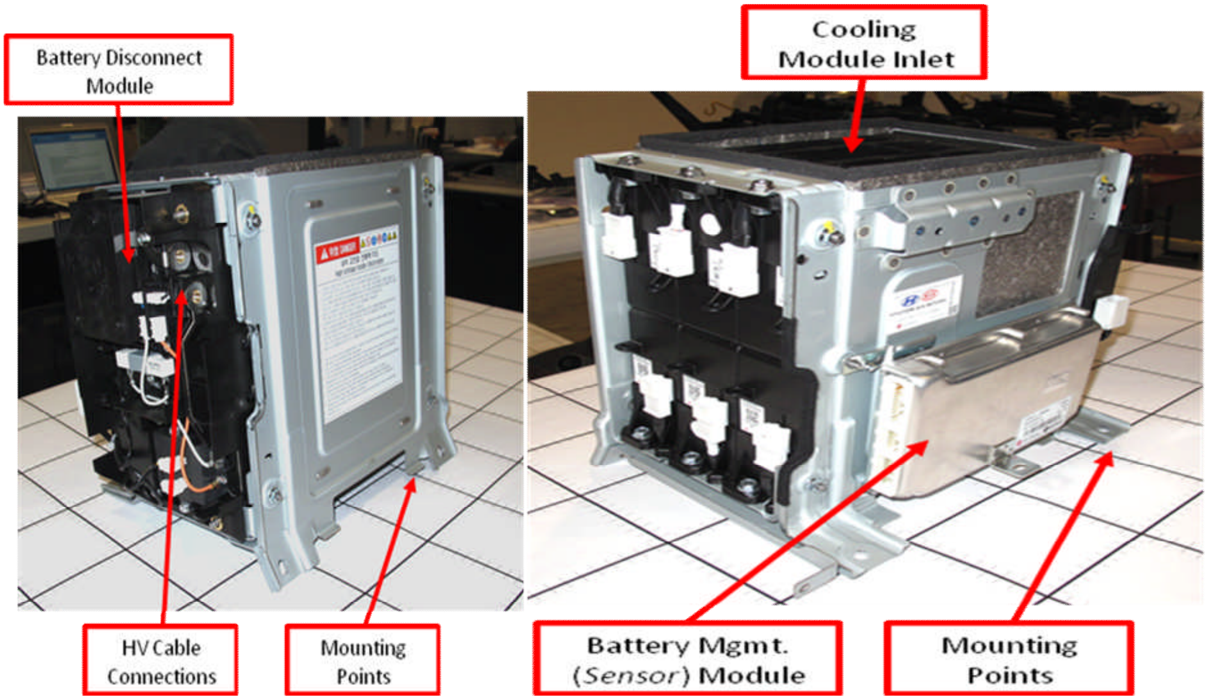


Figure G-1: Li Ion Battery Pack

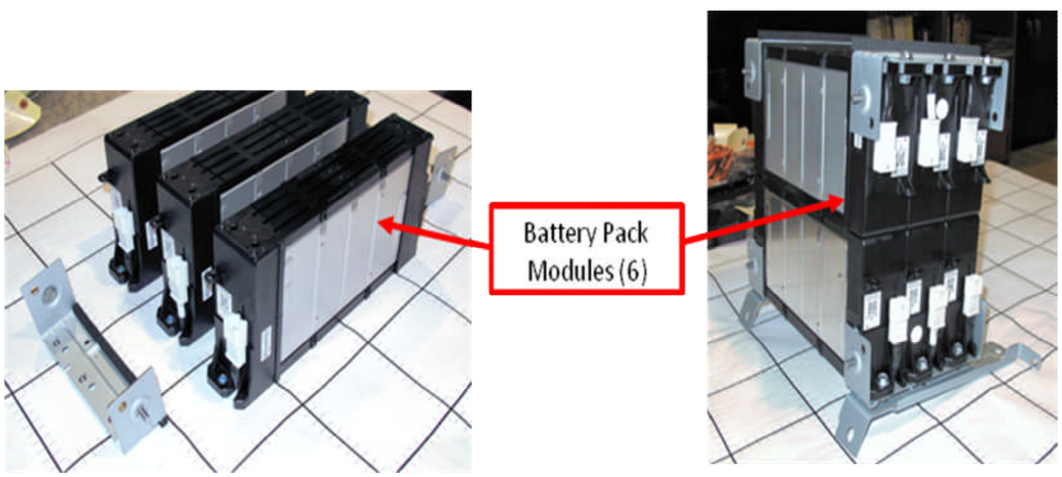


Figure G-2: Li Ion Battery Modules (6)

Each individual module has aluminum cell covers which hold the polymer cells in place providing stiffening and assist in thermal transfer of heat aiding the cooling of the cells.

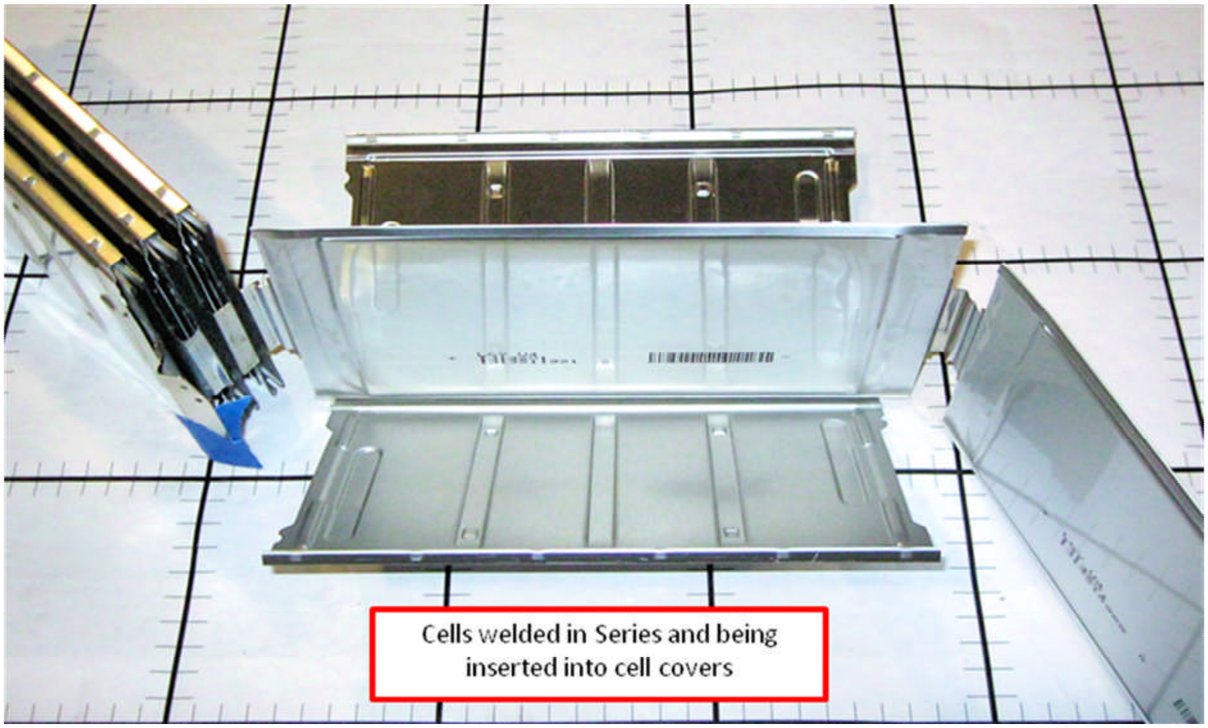


Figure G-3: Li Ion Battery Modules Contain Eight (8) Pouch-Cells Connected in Series with pairs of cells mounted in the cell covers.

The polymer cell construction at the most basic level consists of a sealed metalized polymer pouch with an anode and cathode electrode prismatic stack separated by ceramic coated polymer separator. The tabs of the electrode stacks are ultrasonically welded and a nickel current collector is laser welded to the tabs. **Figure G-4** shows the basic structure of the pouch cell.

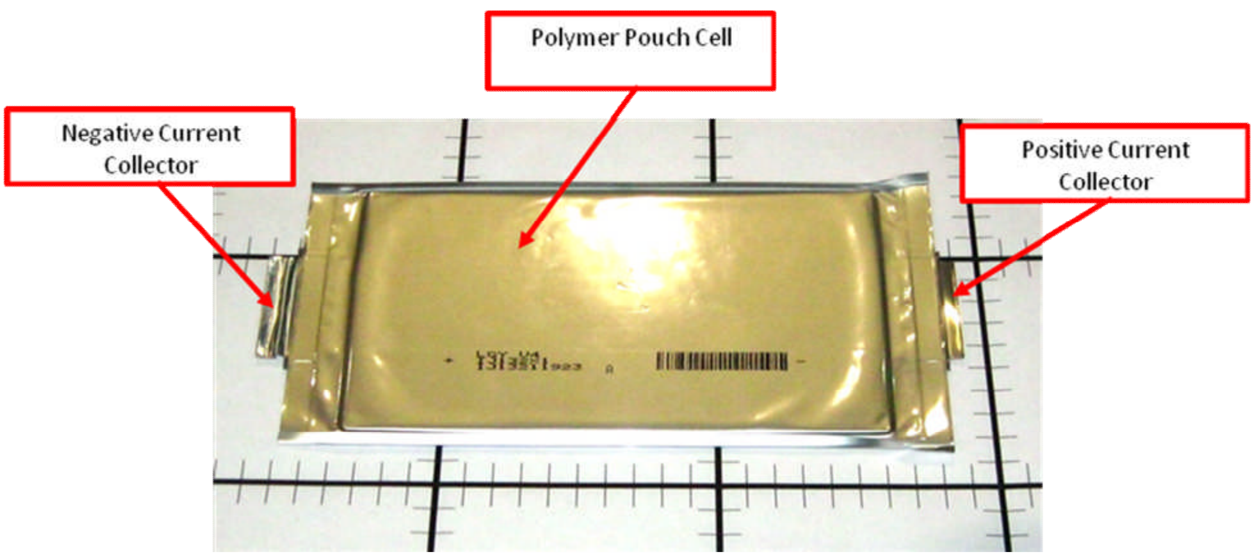


Figure G-4: Lithium Polymer Cell Construction

The Cell Electrode stack uses a "stack and wrap" separator configuration that aids in keeping the individual electrode plates in close contact. After two (2) electrodes and two (2) loose separator sections are placed on the stack, the stack is rotated with one single separator to wrap and hold the stack tight and eliminate separation of the electrodes during charge and discharge of the cell (**Figure G-5**).

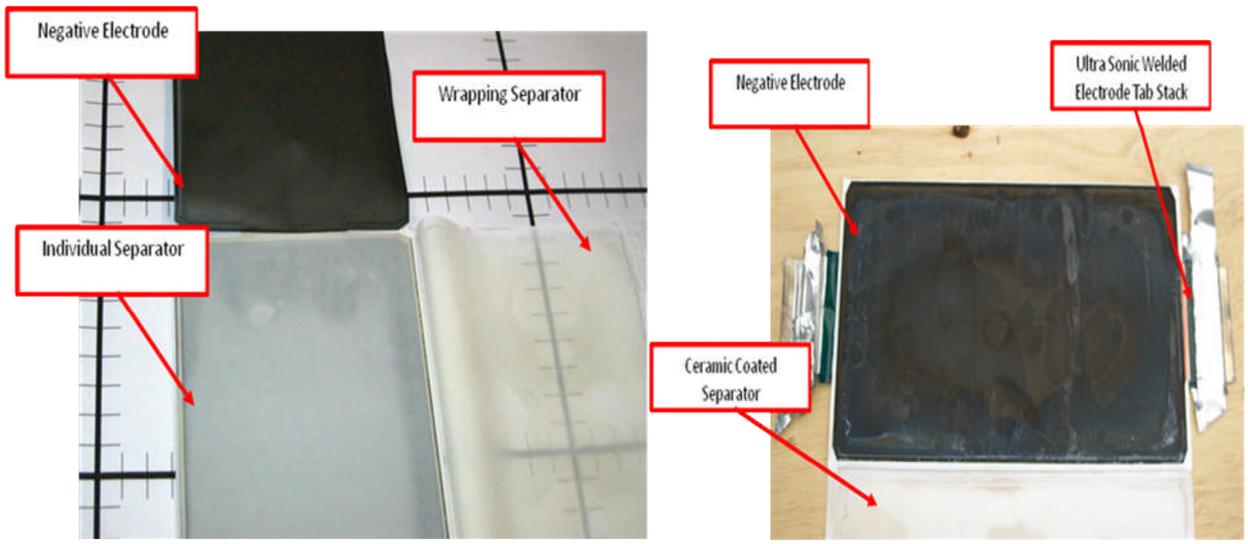


Figure G-5 : Cell with Polymer cover removed

The current collectors of each individual cell are welded to provide a connection point for the voltage sensing and balancing connector (**Error! Reference source not found.**). The connectors contact the rectangular features formed from the welding of the cell current collectors by contact pressure. The connectors are held in place by a clip inserted into the module frame.

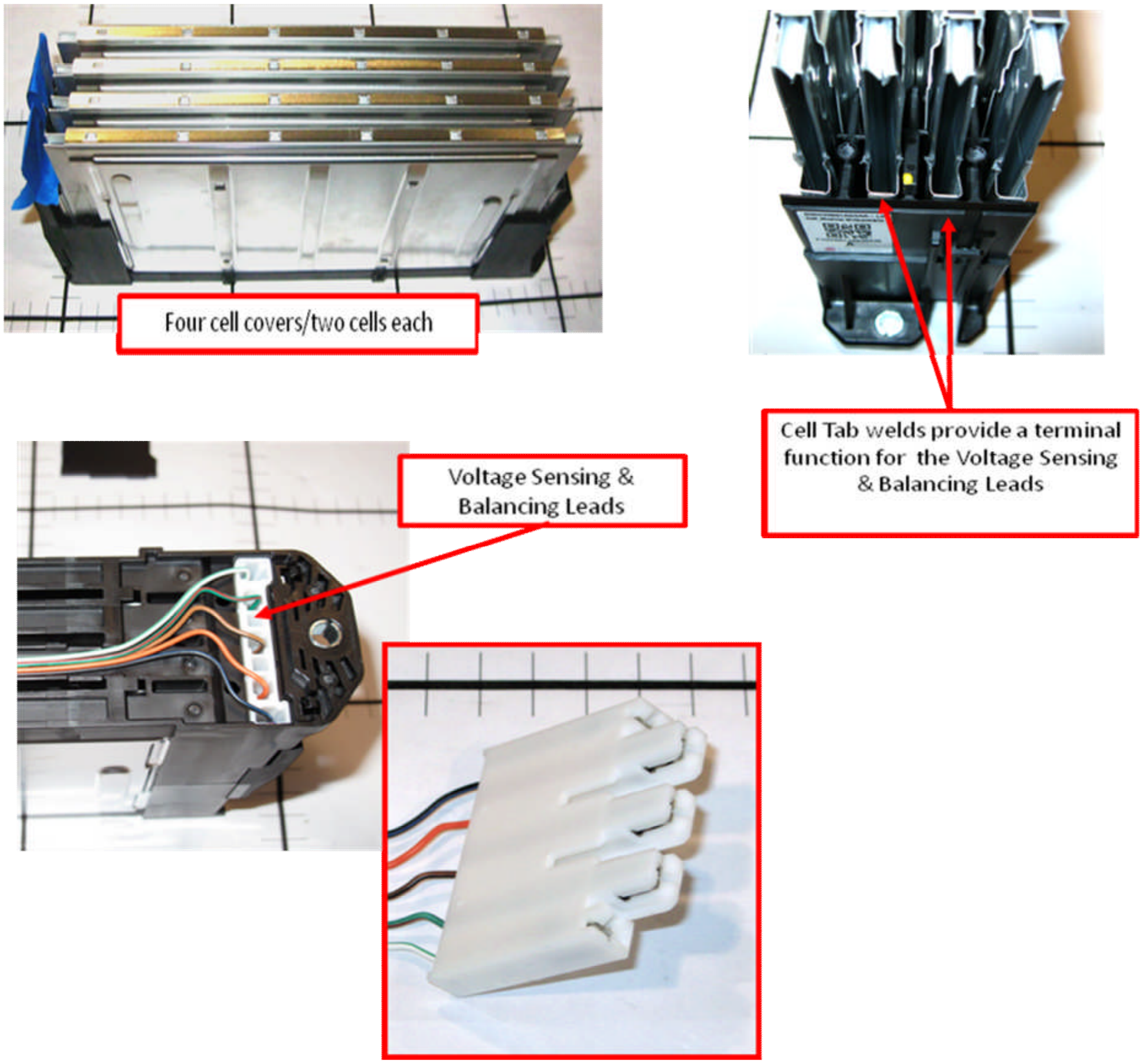


Figure G-6: Cell Covers in Module, Cell Tabs Welded, Voltage Sensing and Cell Balancing Leads

Circuit connections between the individual modules are small buss bars located on front of the pack assembly (**Figure G-6**).

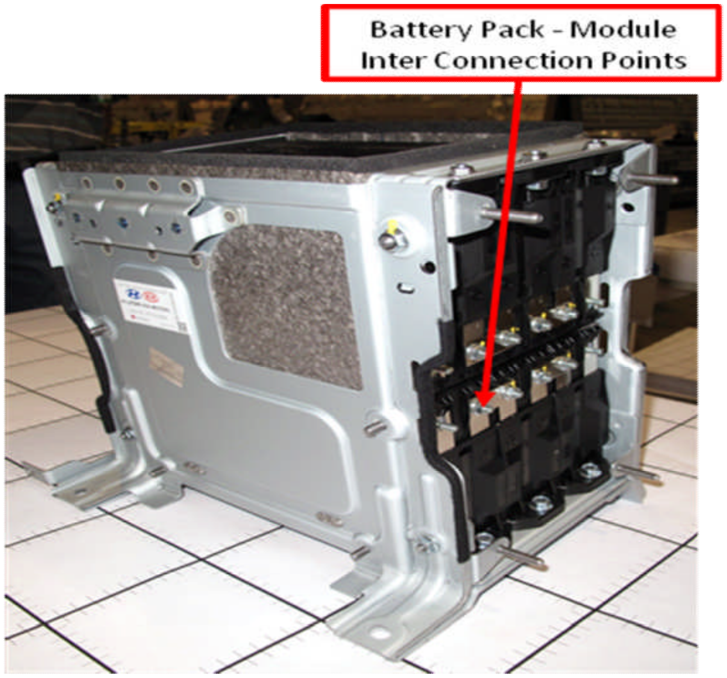


Figure G-7: Battery Pack Front (connection) Side

Stamped steel covers (**Figure G-7**) are employed to closeout and provide mounts for the battery pack. The two (2) side plates are bolted to four (4) cross members, which are also made as steel stampings that incorporate the main mounting structure for the battery pack.

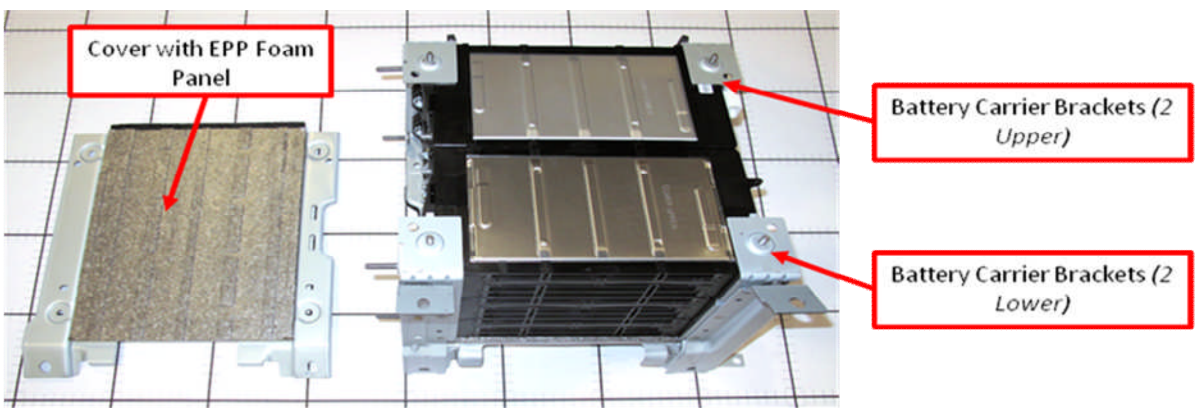


Figure G-8: Stamped Cover Plate

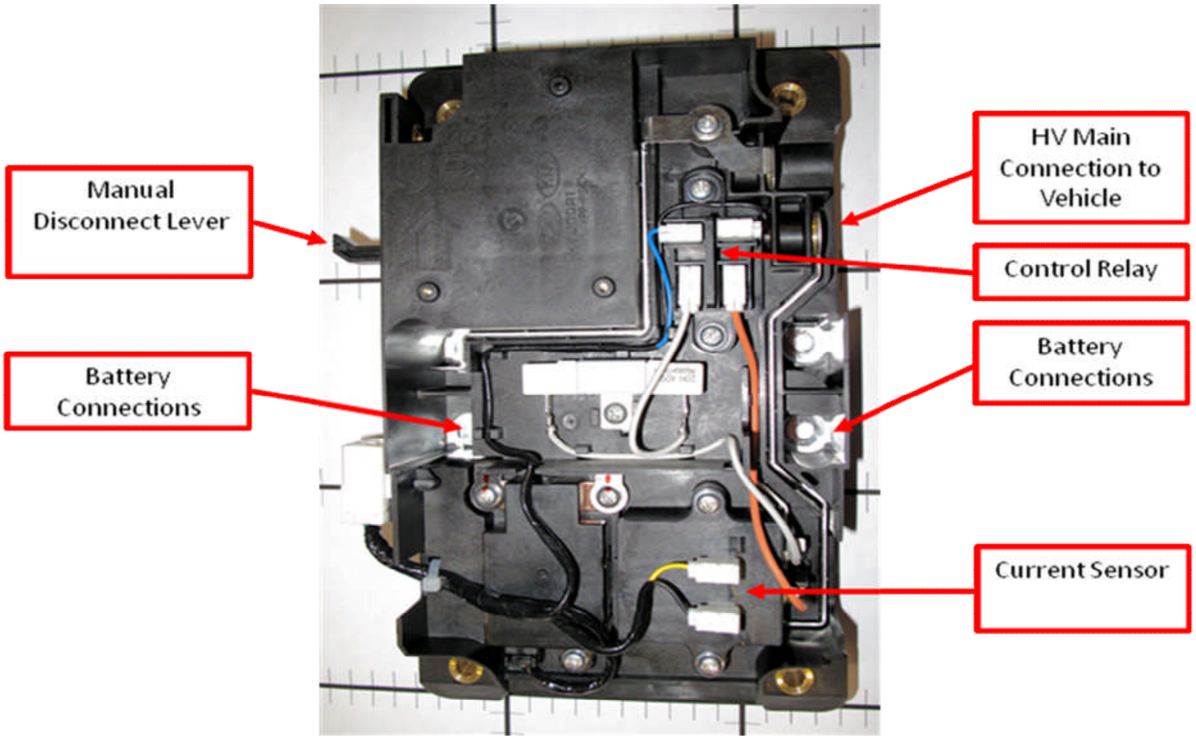


Figure G-9: The Battery Pack Disconnect Module

The battery pack disconnects module, (**Figure G-9**) which mounts to the front of the pack (module connection side of the pack), houses all of the high voltage control units and the module current sensor that interfaces with the battery management control board.

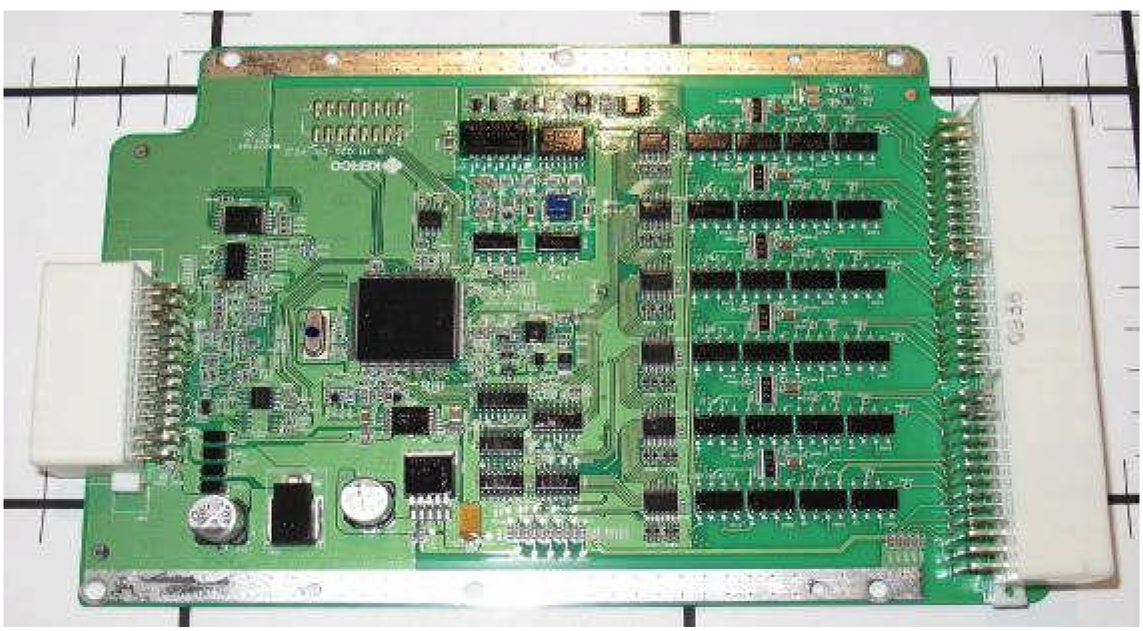


Figure G-10: The Battery Management Control Board

The battery management control board (**Figure G-10**) has a chip set for each individual cell of the battery pack. The chip set controls the charge and discharge rates of each individual cell and monitors charge values to maintain balance of the cells in each individual module. Each of the modules has a master control chip that controls the balance of charge for each module to maintain balance in the overall battery pack.

G.1.1.2 Lithium Polymer Electrical Power Supply Cost Impact

For the lithium polymer high voltage traction battery (LIB) analysis, four (4) main sub-subsystems were evaluated for cost:

- Traction Battery Modules (i.e., 6 - 30V modules)
- Traction Battery Relays, Fuses, Disconnects, etc.
- Traction Battery Sensing & Control Modules
- Assembly of High Voltage Traction Battery Subsystem

The costs for the sub-subsystems listed above can be found in **Table G-2**. To compensate for missing sub-subsystems not included with the evaluated service parts, the Ford Fusion HEV vehicle cost analysis results were utilized. These surrogate subsystem costs, which included costs for components such as the battery cooling module, energy control module, low voltage battery wire harness connections, and assembly of the battery to the vehicle were scaled primarily by battery capacity. The results of the scaling can be found in **Table A-5**, under System ID H.3.

Table G-2: 2010 Hyundai Avante Lithium Polymer High Voltage Traction Battery Cost Analysis

FEV **Technology Level:** Lithium Polymer High Voltage Traction Battery
Vehicle Class: Small Size Passenger Vehicle, 2-4 Passengers
Study Case#: N0501 (N=New, B=Base, 04=Technology Package, 02=Vehicle Class)

NEW TECHNOLOGY PACKAGE COST INFORMATION Lithium Polymer High Voltage Traction Battery - 2010 Hyundai Avante (180V, 5.3Ah, 0.954kWh, 6 modules, 30 volts/module)			NEW TECHNOLOGY PACKAGE QUOTE PARAMETERS				NEW TECHNOLOGY PACKAGE COST INFORMATION Lithium Polymer High Voltage Traction Battery - 2010 Hyundai Avante (180V, 5.3Ah, 0.954kWh, 6 modules, 30 volts/module)										
							Manufacturing				Markup						
Item	Name/Description	Part Number	QTY/ Subsystem	Full, Modification, Differential, or Not Applicable Quote Level	Scaling Factor (Default =1)	Notes	Material	Labor	Burden	Total Manufacturing Cost (Component/ Assembly)	End Item Scrap	SG&A	Profit	ED&T-R&D	Total Markup Cost (Component/ Assembly)	Total Packaging Cost (Component/ Assembly)	Net Component/ Assembly Cost Impact to OEM
0							$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
							$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
	140300 High Voltage Traction Battery Subsystem																
1	**00 Assembly of High Voltage Traction Battery Subsystem**						$ 5.67	$ 6.83	$ 12.99	$ 25.49	$ 0.21	$ 3.19	$ 2.59	$ 0.70	$ 32.17	$ -	$ 32.17
	A Hy Battery Assembly (Assembly of Modules into Final Battery Pack)	14 03 00 - N0502 - 01	1	Full	1	2010 Hyundai Avante h/w	$ 5.67	$ 6.83	$ 12.99	$ 25.49	$ 0.21	$ 3.19	$ 2.59	$ 0.70	$ 32.17	$ -	$ 32.17
2	**01 Traction Battery Modules**		1				$ 284.68	$ 179.28	$ 153.96	$ 617.92	$ 14.30	$ 44.88	$ 50.13	$ 24.49	$ 133.79	$ 0.75	$ 752.47
	A Hy Cell Asm, Cell Module (8 cells/module)	14 03 01 - N0502 - 01	6	Full	1	2010 Hyundai Avante h/w	$ 24.71	$ 9.68	$ 10.36	$ 44.75	$ 0.28	$ 4.06	$ 3.48	$ 1.16	$ 8.99	$ -	$ 53.75
	A.1 HV Battery, 30 volt modules	14 03 01 - N0502 - 02	6			2010 Hyundai Avante h/w	$ 259.97	$ 169.60	$ 143.60	$ 573.17	$ 14.01	$ 40.82	$ 46.65	$ 23.32	$ 124.80	$ 0.75	$ 698.72
3	**02 Traction Battery Relays, Fuses, Disconnects, etc.**						$ 59.22	$ 10.08	$ 10.86	$ 80.17	$ 0.52	$ 7.32	$ 6.35	$ 2.13	$ 16.32	$ -	$ 96.49
	B Battery Disconnect Module (BDM)	14 03 04 - N0502 - 03	1	Full	1	2010 Hyundai Avante h/w	$ 53.61	$ 8.65	$ 6.08	$ 68.34	$ 0.43	$ 6.09	$ 5.24	$ 1.77	$ 13.53	$ -	$ 81.87
	B.1 Current Sensor, BDM	14 03 04 - N0502 - 04	1	Full	1	2010 Hyundai Avante h/w	$ 0.40	$ 0.57	$ 1.16	$ 2.13	$ 0.02	$ 0.27	$ 0.22	$ 0.06	$ 0.57	$ -	$ 2.69
	B1.1. PCB Asm, Current Sensor	14 03 04 - N0502 - 05	1	Full	1	2010 Hyundai Avante h/w	$ 5.22	$ 0.86	$ 3.62	$ 9.70	$ 0.07	$ 0.96	$ 0.89	$ 0.30	$ 2.23	$ -	$ 11.92
5	**04 Traction Battery Sensing & Control Modules**		1				$ 164.89	$ 1.53	$ 3.62	$ 170.05	$ 0.88	$ 11.47	$ 10.55	$ 4.30	$ 27.20	$ -	$ 197.25
	A Battery Management Module (BMM)	14 03 04 - N0502 - 01	1	Full	1	2010 Hyundai Avante h/w	$ 1.54	$ 0.72	$ 0.94	$ 3.19	$ 0.02	$ 0.36	$ 0.30	$ 0.09	$ 0.77	$ -	$ 3.96
	A.1 PCB Asm, Populated, BMM	14 03 04 - N0502 - 02	1	Full	1	2010 Hyundai Avante h/w	$ 163.35	$ 0.82	$ 2.69	$ 166.85	$ 0.85	$ 11.11	$ 10.25	$ 4.22	$ 26.43	$ -	$ 193.28
			Complete Subsystem Quote (Yes/No)			**No**	$ 514.46	$ 197.72	$ 181.44	$ 893.62	$ 15.90	$ 66.86	$ 69.62	$ 31.62	$ 209.49	$ 0.75	$ 1,078.37

H. P2 Scaling Cost Analysis

H.1 P2 Methodology Overview

The P2 hybrid incremental direct manufacturing costs were developed using a similar scaling methodology as used in the power-split scaling analysis. In addition to using cost data developed in the Ford Fusion HEV power-split analysis (case study #0502), data generated from the 2010 Hyundai Avante lithium polymer battery analysis (case study #0501), and VW Jetta wet dual clutch transmission (DCT) cost analysis (case study #0902) were also used. For the P2 HEV configuration, a lithium polymer battery replaced the NiMH battery evaluated in the Ford Fusion power-split analysis.

The basic P2 configuration evaluated, shown in **Figure A-3**, consists of an integrated electric motor/generator and hydraulic clutch assembly positioned between a downsized internal combustion engine (ICE) and transmission. The electrical power supply/storage system consisted of high voltage lithium polymer battery pack; voltage and capacity matched to the electric motor/generator size and vehicle mass.

The P2 HEV analysis consisted of six (6) vehicle classes as shown in **Table H-1**. Similar to the power-split HEV scaling analysis, establishing the baseline technology configuration (with defined powertrain and vehicle parameters) for each vehicle class was the first step in the analysis. From the baseline configurations, a vehicle curb weight reduction was applied to selected vehicle segments (Reference Table A-2). The reduction in mass supported reductions in net maximum system power and torque, the exact amount dependent on vehicle segment. The mass reduction projections were estimations established by the EPA team.

Applying ICE and traction motor/generator sizing ratios with matched battery capacities, the P2 primary powertain component sizes were established. The ICE and traction motor/generator ratios, along with battery sizing recommendations, were also provided by the EPA team. More details on the development of the primary P2 powertrain components will be discussed in Section H.2.

Once the primary powertrain components were established, component costs within each subsystem/system were developed using manufacturing cost-to-component size ratios developed in the Ford Fusion, Hyundai Avante, and VW Jetta cost analyses referenced previously. Both the primary base components (e.g., traction motor, high voltage traction battery) and selected vehicle segment attributes (e.g., vehicle footprint, passenger volume, curb weight) were used to develop the scaling ratios. Included in the process of scaling primary components, assumptions were made on what additional supporting/ancillary components were required to complete the assembly, subsystem, or system. This was required due to the fact that the power-split hardware had to be configured into a P2 architecture.

Table H-1: Baseline Powertrain and Vehicle Attributes for the Additional Vehicle Classes, Under Evaluation for Adding P2 HEV Technology

Vehicle Classification			Baseline Technology Configuration: Internal Combustion Engine (ICE) and Automatic Transmission (2011 Sales-Weighted Baseline Data From EPA)										Downsizing of Conventional Powertrain System, Based on Vehicle Weight Reductions								
Class	Vehicle Class Description	Passenger Capacity	Curb Weight	Emission Test Weight (ETW) Added Weight	ETW	ICE Power Max		ICE Torque Max		Wheel Base	Track	Interior Passenger Volume	Reduced Curb Weight	Emission Test Weight (ETW) Added Weight	ETW	Percent Change in Curb Weight	Percent Change in ETW (Decrease in Powertrain Size)	ICE Power Max with Curb Weight Reduction		ICE Torque Max with Curb Weight Reduction	
			"lbs"	"lbs"	"lbs	"kW"	"hp"	"N*m"	"lb*ft"	"mm"	"mm"	"m³"	"lbs"	"lbs"	"lbs	%	%	"kW"	"hp"	"N*m"	"lb*ft"
1	Subcompact Size Passenger Vehicle	Passenger (2-4)	2628	300	2928	95.6	128.11	170.8	126.0	2565.40	1498.60	2.535	2628	300	2928	0.00%	0.00%	95.6	128.11	170.8	126.0
2	Compact/ Small Size Passenger Vehicle	Passenger (2-5)	3118	300	3418	115.3	154.52	203.4	150.0	2717.80	1549.40	2.693	3056	300	3356	-2.00%	-1.82%	113.2	151.70	199.7	147.3
3	Mid/Large Size Passenger Vehicle	Passenger (4-6)	3751	300	4051	198.8	266.48	352.5	260.0	2794.00	1574.80	2.898	3376	300	3676	-10.00%	-9.26%	180.4	241.81	319.9	235.9
4	Minivan/ Large Size Passenger Vehicle	Passenger (6-8)	4087	300	4387	173.9	233.16	317.2	234.0	2819.40	1600.20	3.618	3433	300	3733	-16.00%	-14.91%	148.0	198.40	270.0	199.1
5	Small/ Mid Size Truck	Passenger + Midsize Towing Capabilities	3849	300	4149	156.4	209.68	321.3	237.00	2717.80	1549.40	3.318	3233	300	3533	-16.00%	-14.84%	133.2	178.56	273.6	201.8
6	Large Truck	Passenger or Commercial + Strong Towing Capabilities	4646	300	4946	196.1	262.92	393.2	290.00	3124.20	1651.00	3.194	3949	300	4249	-15.00%	-14.09%	168.5	225.87	337.8	249.1

For example, the traction motor/generator assembly is the primary component within the integrated traction motor/generator and clutch assembly. To support the traction motor/generator, a defined level of power electronics, lubrication, cooling, wet clutch components, etc. are required. All are considered part of the integrated traction motor/generator and clutch assembly. Once these additional components were identified in the analysis, a size/performance estimation was made. Developing a size/performance ratio to the existing costed hardware (i.e., from Fusion, Hyundai, and VW analyses), a cost for the P2 hardware could be calculated.

The scaled totals for each system were then added together to create an estimated P2 vehicle cost for each vehicle classification.

Within the scope of this analysis, no consideration was given to selecting an ICE or transmission technology configuration, nor was a downsizing credit calculated for either of these two (2) systems. The net incremental direct manufacturing costs provided in Table A-3, for each system and vehicle segment evaluated are representative of adding a

P2 HEV system to a conventional powertrain configuration already downsized per the assumptions outlined previously (i.e., 20% vehicle mass reduction + assumption ICE can be further reduced as result of electric motor addition).

H.2: P2 Component Sizing

The first step in sizing key P2 HEV powertrain components was to establish the baseline powertrain and vehicle attributes for each selected vehicle class. **Table H-1** provides the baseline powertrain and vehicle attributes used in the analysis. The values are based on EPA-acquired, 2008 sales-weighted average data.

A mass reduction was then applied to the curb weight for selected vehicle classes to establish projected curb weights for the 2017 and beyond timeframe. The percent change in the Emission Test Weight (i.e., curb weight + 300 lbs) for the baseline technology configurations versus the mass-reduced vehicles was then used to estimate the conventional ICE max power and torque requirements for the mass-reduced vehicles (**Table H-1**).

The final step in the sizing segment of the analysis was to establish the ICE, traction motor/generator, and high voltage traction battery size for each of the vehicle classifications. This was accomplished by applying sizing ratios, provided by the EPA team, to the mass-reduced, conventional powertrain, ICE power specifications. The sizing ratios are shown in **Table H-2** with the corresponding calculated ICE and traction motor/generator maximum power specifications. For all vehicle classification segments, other than large truck, the same sizing assumption was made. That is, 100% of the conventional powertrain power and torque were maintained for the P2 configuration with an 80/20 ICE to traction motor-generator power split. For the large truck segment the ICE was not downsized, with an additional 20% of power being added via the traction motor/generator.

The traction battery nominal battery capacities "kWh" were also provide by the EPA team for each vehicle class (**Table H-2**). A size ratio was then established between the capacities provided for each vehicle class versus the 2010 Hyundai Avante lithium polymer battery (180V 5.3Ah, 0.954 kWh). Battery packs sizes, based on the Hyundai Avante battery, were then developed for each of the vehicle segments. Since ground-up costs were already developed for the Hyundai battery modules, scaling module/cell costs to other vehicle classes was relatively straight-forward.

Table H-2: Primary Component Sizing for a Range of P2 Hybrid Electric Vehicles Classes

Vehicle Classification			New P2 Technology Configuration: ICE, Electric Motor/Generator, Transmission, and Lithium Polymer Battery																			
Class	Vehicle Class Description	Passenger Capacity	Max Power & Torque of HEV Powertrain as Percent of Conventional Powertrain System.	Size of Internal Combustion Engine (ICE), as a Percent of Net System Power	Size of Traction Motor/ Generator, as a Percent of Net System Power	High Voltage Battery Max Power, as a Percent of Electric Motor Max Power	Maximum System Power		Maximum System Torque		Maximum ICE Power & Torque				Maximum Traction Motor Power Calculated		EPA Recommended Battery Specification		Battery Sizing Based On 2010 Hyundai Avante Lithium Polymer Battery (180V, 5.3Ah, 0.954kWh) Battery Construction: 6 Modules, 8 Cells/Module, Total 48 Cells			
			%	"%"	"%"	"N*m"	"kW"	"hp"	"N*m"	"lb*ft"	"kW"	"hp"	"N*m"	"lb*ft"	"kW"	"hp"	Max Nominal Power Rating "kW"	Nominal Battery Capacity "kWh"	Percent Capacity of Hyundai Avante Battery (0.954kWh)	Number of Battery Cells Based on Hyundai Avante Battery	Number of Modules	Estimated Battery Voltage Based on Hyundai Avante Battery (5.3Ah)
1	Subcompact Size Passenger Vehicle	Passenger (2-4)	100.00%	80.00%	20.00%	100.00%	95.6	128.1	170.8	126.0	76.5	102.49	136.7	100.8	19.11	25.6	19.11	0.8087	0.85	41	5.13	152.59
2	Compact/ Small Size Passenger Vehicle	Passenger (2-5)	100.00%	80.00%	20.00%	100.00%	113.2	151.7	199.7	147.3	90.5	121.36	159.7	117.8	22.63	30.3	22.63	0.9268	0.97	47	5.88	174.86
3	Mid/Large Size Passenger Vehicle	Passenger (4-6)	100.00%	80.00%	20.00%	100.00%	180.4	241.8	319.9	235.9	144.3	193.45	255.9	188.7	36.08	48.4	36.08	1.0153	1.06	52	6.50	191.56
4	Minivan/ Large Size Passenger Vehicle	Passenger (6-8)	100.00%	80.00%	20.00%	100.00%	148.0	198.4	270.0	199.1	118.4	158.72	216.0	159.3	29.60	39.7	29.60	1.0312	1.08	52	6.50	194.56
5	Small/ Mid Size Truck	Passenger + Midsize Towing Capabilities	100.00%	80.00%	20.00%	100.00%	133.2	178.6	273.6	201.8	106.6	142.85	218.9	161.5	26.64	35.7	26.64	0.9758	1.02	50	6.25	184.12
6	Large Truck	Passenger or Commercial + Strong Towing Capabilities	100.00%	100.00%	20.00%	100.00%	168.5	225.9	337.8	249.1	168.5	225.87	337.8	249.1	33.70	45.2	33.70	1.1736	1.23	60	7.50	221.44

H.3 System Scaling Overview

The scaling methodology used to develop P2 HEV, net incremental, direct manufacturing costs for a range of vehicle classes was very similar to the approach used in the power-split analysis. The only difference was an additional assumption step in which selected power-split hardware had to be deleted, modified or added to fit the P2 HEV configuration. The most extreme case of this was taking the eCVT for the power-split and eliminating components (e.g., gearing, generator, generator control unit) modifying components (e.g., power electronics components, transmission control unit, lubrication subsystem) and adding components (e.g., dual mass flywheel, wet clutch, case material for wet clutch) to arrive at an integrated electric traction motor/generator and clutch assembly.

In **Table A-3**, a summary of the net incremental, direct manufacturing costs to add P2 HEV technology to a range of vehicle segments are presented on a system level. **Table A-4** and **Table A-5** provide additional cost details, at the component and subsystem level, for the integrated electric motor/generator and clutch assembly system and the high voltage traction battery, respectively. These subsystems account for approximately 80% of the net cost impact for adding the P2 technology configuration.

I. Glossary of Terms

Assembly: a group of interdependent components joined together to perform a defined function (e.g., turbocharger assembly, high pressure fuel pump assembly, high pressure fuel injector assembly).

Buy: the components or assemblies a manufacturer would purchase versus manufacture. All designated "buy" parts, within the analysis, only have a net component cost presented. These types of parts are typically considered commodity purchase parts having industry established pricing.

CBOM (Comparison Bill of Materials): a system bill of materials, identifying all the subsystems, assemblies, and components associated with the technology configurations under evaluation. The CBOM records all the high-level details of the technology configurations under study, identifies those items which have cost implication as a result of the new versus base technology differences, documents the study assumptions, and is the primary document for capturing input from the cross-functional team.

Component: the lowest level part within the cost analysis. An assembly is typically made up of several components acting together to perform a function (e.g., the turbine wheel in a turbocharger assembly). However, in some cases, a component can independently perform a function within a sub-subsystem or subsystem (e.g., exhaust manifold within the exhaust subsystem).

Cost Estimating Models: cost estimating tools, external to the Design Profit® software, used to calculate operation and process parameters for primary manufacturing processes (e.g., injection molding, die casting, metal stamping, forging). Key information calculated from the costing estimating tools (e.g., cycle times, raw material usage, equipment size) is inputted into the Lean Design® process maps supporting the cost analysis. The Excel base cost estimating models are developed and validated by Munro & Associates.

Costing Databases: the five (5) core databases that contain all the cost rates for the analysis. (1) The **material database** lists all the materials used throughout the analysis along with the estimated price/pound for each. (2) The **labor database** captures various automotive, direct labor, manufacturing jobs (supplier and OEM), along with the associated mean hourly labor rates. (3) The **manufacturing overhead rate database** contains the cost/hour for the various pieces of manufacturing equipment assumed in the analysis. (4) A **mark-up database** assigns a percentage of mark-up for each of the four (4) main mark-up categories (i.e., end-item scrap, SG&A, profit, and ED&T), based on the industry, supplier size, and complexity classification. (5) The **packaging database**, contains packaging options and costs for each case.

Lean Design® (a module within the *Design Profit® software*): is used to create detailed process flow charts/process maps. Lean Design® uses a series of standardized symbols, with each base symbol representing a group of similar manufacturing procedures (e.g., fastening, material modifications, inspection). For each group, a Lean Design® library/database exists containing standardized operations along with the associated manufacturing information and specifications for each operation. The information and specifications are used to generate a net operation cycle time. Each operation on a process flow chart is represented by a base symbol, operation description, and operation time, all linked to a Lean Design® library/database.

Make: terminology used to identify those components or assemblies a manufacturer would produce internally versus purchase. All parts designated as a "make" part, within the analysis, are costed in full detail.

MAQS (Manufacturing Assumption and Quote Summary) worksheet: standardized template used in the analysis to calculate the mass production manufacturing cost, including supplier mark-up, for each system, subsystem, and assembly quoted in the analysis. Every component and assembly costed in the analysis will have a MAQS worksheet. The worksheet is based on a standard OEM (original equipment manufacturer) quote sheet modified for improved costing transparency and flexibility in sensitivity studies. The main feeder documents to the MAQS worksheets are **process maps** and the **costing databases**.

MCRs (Material Cost Reductions): a process employed to identify and capture potential design and/or manufacturing optimization ideas with the hardware under evaluation. These savings could potentially reduce or increase the differential costs between the new and base technology configurations, depending on whether an MCR idea is for the new or the base technology.

Net Component/Assembly Cost Impact to OEM: the net manufacturing cost impact per unit to the OEM for a defined component, assembly, subsystem, or system. For components produced by the supplier base, the net manufacturing cost impact to the OEM includes total manufacturing costs (material, labor, and manufacturing overhead), mark-up (end-item scrap costs, selling, general and administrative costs, profit, and engineering design and testing costs) and packaging costs. For OEM internally manufactured components, the net manufacturing cost impact to the OEM includes total manufacturing costs and packaging costs; mark-up costs are addressed through the application of an indirect cost multiplier.

NTAs (New Technology Advances): a process employed to identify and capture alternative advance technology ideas which could be substituted for some of the existing hardware under evaluation. These advanced technologies, through improved function and performance, and/or cost reductions, could help increase the overall value of the technology configuration.

Powertrain Package Proforma: a summary worksheet comparing the key physical and performance attributes of the technology under study with those of the corresponding base configuration.

Process Maps: detailed process flow charts used to capture the operations and processes and associated key manufacturing variables involved in manufacturing products at any level (e.g., vehicle, system, subsystem, assembly, component).

P-VCSM (Powertrain–Vehicle Class Summary Matrix): records the technologies being evaluated, the applicable vehicle classes for each technology, and key parameters for vehicles or vehicle systems that have been selected to represent the new technology and baseline configurations in each vehicle class to be costed.

Quote: the analytical process of establishing a cost for a component or assembly.

Sub-subsystem: a group of interdependent assemblies and/or components, required to create a functioning sub-subsystem. For example, the air induction subsystem contains several sub-subsystems including turbocharging, heat exchangers, pipes, hoses, and ducting.

Subsystem: a group of interdependent sub-subsystems, assemblies and/or components, required to create a functioning subsystem. For example, the engine system contains several subsystems including crank drive subsystem, cylinder block subsystem, cylinder head subsystem, fuel induction subsystem, and air induction subsystem.

Subsystem CMAT (Cost Model Analysis Templates): the document used to display and roll up all the sub-subsystem, assembly, and component incremental costs associated with a subsystem (e.g., fuel induction, air induction, exhaust), as defined by the Comparison Bill of Material (CBOM).

Surrogate part: a part similar in fit, form, and function as another part that is required for the cost analysis. Surrogate parts are sometimes used in the cost analysis when actual parts are unavailable. The surrogate part's cost is considered equivalent to the actual part's cost.

System: a group of interdependent subsystems, sub-subsystems, assemblies, and/or components working together to create a vehicle primary function (e.g., engine system, transmission system, brake system, fuel system, suspension system).

System CMAT (Cost Model Analysis Template): the document used to display and roll up all the subsystem incremental costs associated with a system (e.g., engine, transmission, steering) as defined by the CBOMs.