

Teardown-Based Cost Assessment for Use in Setting Greenhouse Gas Emissions Standards

Gregory Kolwich
FEV, Inc.

Al Steier
Munro & Associates

Don Kopinski, Brian Nelson, David Ganss, Benjamin Ellies, Jeff Cherry and Michael Olechiw
U.S. Environmental Protection Agency

Thomas Casciani
FEV Inc

Antonio Fernandez
EPA

ABSTRACT

The U.S. Environmental Protection Agency (EPA) contracted with FEV, Inc. to estimate the per-vehicle cost of employing selected advanced efficiency-improving technologies in light-duty motor vehicles. The development of transparent, reliable cost analyses that are accessible to all interested stakeholders has played a crucial role in establishing feasible and cost effective standards to improve fuel economy and reduce greenhouse gas (GHG) emissions.

The FEV team, together with engineering staff from EPA's National Vehicle and Fuel Emissions Laboratory, and FEV's subcontractor, Munro & Associates, developed a robust costing methodology based on tearing down, to the piece part level, relevant systems, sub-systems, and assemblies from vehicles "with and without" the technologies being evaluated. The parts found to be redesigned, added, or deleted to implement the new technologies were then examined by the team's manufacturing experts to assess their material composition and sequence of fabrication steps. Finally, using information from comprehensive costing databases for raw materials, labor rates, manufacturing overhead, and mark-up costs, each technology's direct manufacturing cost was determined. Where appropriate, these results were scaled to other vehicle sizes and to similar technologies, and sensitivity analyses of key inputs such as raw material costs were performed. Marketplace validation was conducted at all stages of the analysis by cross-checking with data developed by entities and processes external to the team.

Costed technologies include:

- mild and full parallel hybrid electric vehicles (HEVs)
- turbocharged, downsized gasoline direct-injection (GDI) engines
- 6- and 8-speed automatic and dual-clutch transmissions (DCTs)
- hydraulically-actuated variable valve timing and lift (VVT/L)
- electrically-driven air conditioning compressor

In addition to this work already completed for EPA, additional case studies are underway looking at advanced high pressure diesel engine technologies, exhaust gas recirculation systems and micro hybrid technology configurations. These studies have been commissioned by the International Council on Clean Transportation (ICCT) for the European light-duty vehicle market.

This paper presents the methodology and results of the work done by FEV and Munro for EPA, along with a number of lessons learned by the team along the way. This approach to costing new technologies has proven to be very robust and of substantial value in recent standards-setting activities related to light-duty vehicle GHGs and fuel economy. Its success makes it likely that this approach will continue to find use in the future, not only in government standards setting activities, but also for private interests with a desire to provide, for all to see, an understanding of the cost of applying innovative technologies to products in the transportation sector.

CITATION: Kolwich, G., Steier, A., Kopinski, D., Nelson, B. et al., "Teardown-Based Cost Assessment for Use in Setting Greenhouse Gas Emissions Standards," *SAE Int. J. Passeng. Cars - Mech. Syst.* 5(2):2012, doi:10.4271/2012-01-1343

INTRODUCTION

EPA's motor vehicle emissions control program is now in its fifth decade. Its success has been technology-driven from the start and, as a result, the projected cost of adding new technology to vehicles has always been a key consideration in EPA policy decisions. In establishing EPA's authority to regulate motor vehicle emissions, Congress directed that any such regulations "shall take effect after such period as the Administrator finds necessary to permit the development and application of the requisite technology, *giving appropriate consideration to the cost of compliance* within such period" (Clean Air Act section 202(a)(2), emphasis added). Even so, the importance and challenge of performing accurate cost estimation has grown in recent years:

- Unlike past EPA actions in which technology costing has been a straightforward and standalone analysis to support rulemaking conclusions, the rulemakings EPA has recently undertaken jointly with the National Highway Traffic Safety Administration (NHTSA) to reduce light-duty vehicle greenhouse gases and fuel consumption depend on cost (and effectiveness) projections for a variety of individual technologies. These projections serve as inputs to sophisticated computer models that predict how manufacturers would likely respond to new standards scenarios.
- The technologies of interest are complex and often involve facets of vehicle integration that are not immediately obvious. (Example: a redesigned rear seat bottom to include channels to help cool hybrid vehicle batteries).
- The cost effectiveness (cost per ton of emissions reduction) has become more critical to decision-making as emissions standards are progressively tightened over time.
- The timeframes over which new standards are to be implemented have lengthened. The joint EPA/NHTSA rulemaking effort currently underway is evaluating fuel economy and GHG emissions standards that do not finish phasing in until well over a decade from now - in 2025. Making reliable cost estimates this far out in time is a challenging exercise.

In contrast to past EPA rulemakings, in which the technology options are largely developed by emission control manufacturers, technologies for reducing GHGs and fuel consumption are so integral to the design of vehicles and their powertrains that much of the technology expertise resides among the vehicle manufacturers. Competitiveness issues may make these companies reticent to make their data public. In addition, because these companies are the directly regulated parties, they may be disinclined to share their cost data with EPA. As a result, when U.S. government efforts were initiated to set new standards for GHG emissions and fuel economy, it was observed that available technology cost estimates varied greatly and were largely based on supplier price quotes and manufacturer statements in the press, neither

of which allowed for independent verification of their accuracy. As noted by the National Academy of Sciences (NAS) Committee on the Assessment of Technologies for Improving Light-Duty Vehicle Fuel Economy: "Available cost estimates are based on a variety of sources: component cost estimates obtained from suppliers, discussions with experts at automobile manufacturers and suppliers, publicly available transaction prices, and comparisons of the prices of similar vehicles with and without a particular technology." The Committee went on to observe that "there is a need for cost estimates based on a teardown of all the elements of a technology and a detailed accounting of materials and capital costs and labor time for all fabrication and assembly processes", and "estimates based on the more rigorous method of teardown analysis would increase confidence in the accuracy of the costs of reducing fuel consumption." [1]

PRINCIPLES

EPA's response to this challenge has been to engage a team of industry experts to perform cost analysis shaped by a set of guiding principles. EPA chose FEV, Inc. to lead this work based on FEV's extensive experience in developing and understanding advanced automotive design and manufacturing technologies, and on EPA's confidence that FEV could provide objective, well-documented results. FEV subsequently engaged Munro & Associates as subcontractor, bringing extensive additional experience in conducting automotive system teardowns and benchmarking. The principles established for the work are:

Transparency - Reliance on proprietary information is minimized, and all costing is based on industry standard manufacturing practices. Analysis details are made available to the public. This principle is probably the most significant aspect of the work that sets it apart from teardown costing done in the past for commercial purposes.

High-Volume Production - Both long-term and short-term (start-up) costs are of interest in standards-setting. To facilitate consistency in the overall analysis, the team chose to focus the teardown-based cost work on long-term costs, with high production volumes (450,000 vehicles assumed) and mature designs, and to account for start-up costs through the application of "reverse learning" curves. The Joint Technical Support Document for the 2017-2025 light-duty vehicle rulemaking proposal provides a discussion of the learning curve methodology [2].

Costs Derived from Real Hardware - Cost information is primarily obtained by tearing down vehicle assemblies, as illustrated in [Figure 1](#), and assessing the raw materials and fabrication processes (assuming standard industry processes) needed to produce and assemble their individual parts (with all appropriate mark-ups). Conversely, supplier price quotes are relied on only for "commodity parts", for which a mature and diverse market already exists to make those quotes reliable for future production. Generally, these are small parts such as screws and o-rings.



Figure 1. Example of a Teardown for Cost Analysis

Domestic Manufacturing Locations - All vehicle and supplier manufacturing is assumed to take place in the U.S. The team considered this assumption appropriate for cost analysis being used to support government standards-setting. To the extent significant manufacturing actually takes place in other countries to reduce costs, this would tend to make the cost estimates conservative (toward the high-side), though the team believes that recent trends (labor rates, shipping costs, etc.) have tended to diminish country-of-origin cost differentials.

Note that there are two internal tensions inherent in this set of principles that had to be managed to yield cost results considered useful for standards-setting. First, hardware-derived costs necessarily involve assessment of “parts on the table”, yet when these parts come from vehicles in only limited production, with not-yet-mature design and manufacturing optimization, cost results may be biased high. The NAS Committee discusses this limitation in its report: “Such teardown studies are costly and are not feasible for advanced technologies whose designs are not yet finalized and/or whose system integration impacts are not yet fully understood.”[1] On the other hand, basing new standards on technologies already widespread and mature in the fleet can hardly be considered technologyforcing, amounting as it would to sanctioning the status quo.

Fortunately, the team found that the culture of innovation present throughout the worldwide automotive market makes it possible to find production vehicles that employ the technologies of interest, albeit with production on a limited scale. Teardown of assemblies from these vehicles, augmented by consideration of design and manufacturing optimizations that could be made to examined hardware not yet designed for high volumes, and further augmented by

application of accepted learning curves in the rulemaking analyses, allowed for robust long-term cost projections.

The second inherent tension needing to be managed is between the transparency objective and the use of teardowns from which thousands of individual pieces of information are gathered and used. The sheer volume of data makes it challenging for people outside the analysis team to review the work in detail. The team worked to overcome this difficulty by documenting all phases of the analysis in standardized templates built from Microsoft Excel spreadsheets. These were placed in EPA's electronic dockets EPA-HQ-OAR-2009-0472 and EPA-HQ-OAR-2010-0799, available at www.regulations.gov, for access by stakeholders wishing to view the details. Photographs of individual parts were included to aid understanding. Intermediate details were captured in mid-level spreadsheet templates and documented in published reports [3,4,5,6,7]. High-level results were carried over into rulemaking documents such as EPA's Regulatory Impact Analysis [8].

INDIRECT COSTS

A number of indirect costs must be added to the direct manufacturing costs in determining how new government standards would affect the total cost impact on consumers. These include costs incurred by the vehicle manufacturer (OEM) for research, development, engineering, corporate salaries, pensions, dealer support, marketing, and profits. By their nature, indirect costs lend themselves to top-down calculation rather than to the bottom-up approach used by the team for determining direct costs. As a result, the team has chosen to pursue the assignment of vehicle manufacturer *indirect* costs through the application of separately-determined indirect cost multipliers (ICMs) to the direct manufacturing costs. Because indirect costs can be sizeable,

and involve their own set of issues, they have been the subject of a number of government and industry analyses, reports and critiques that have paralleled the development of the direct cost methodology covered here [9,10].

In addition to vehicle manufacturer indirect costs, addressed via the above-described ICMs, many of the same categories of indirect costs are also incurred by the component and assembly manufacturers who supply to the vehicle manufacturers (Tier 1 suppliers), or who supply to these suppliers (Tier 2 and Tier 3 suppliers). These indirect costs are not covered by the ICMs and remain within the scope of this cost analysis. Like OEM indirect costs, they by nature do not lend themselves to a bottom-up determination; however, to account for them the team has followed a common industry practice by *assigning* them to individual parts through the application of mark-ups, as explained in the following section. Thus the costs calculated for these supplied assemblies are what the analysis projects the vehicle manufacturers would pay for them in a mature market, and the analysis refers to these costs as “direct” costs, because they represent the direct costs of the hardware to the vehicle manufacturers. These, along with any direct manufacturing costs borne by the vehicle manufacturers, make up the cost elements of the incremental direct manufacturing cost for a technology, as summarized in [Figure 2](#).

METHODOLOGY

Each technology cost is derived from two basic types of information sources. The first is a set of general databases in the form of look-up tables (Excel spreadsheets) that contain all cost data used in the analyses, including material (\$/lb), labor (\$/hour), manufacturing overhead (\$/hour), mark-up (% of total manufacturing cost), and packaging (\$/packaging type). These databases were built from a variety of sources discussed below. They are used across the spectrum of costed technologies. The second type of information is part-specific data obtained from the teardowns, and detailed in production process maps. The process maps were created using Design Profit®, a software application developed by Munro and Associates. Key information from the process maps is transferred and processed into standardized quoting worksheets. The part-specific information includes such items as material composition and weight, and means of fabrication and/or assembly.

GENERAL COSTING INFORMATION- THE COSTING DATABASES

Materials

The pricing information in the materials database is derived from various sources of publicly available data from which historical trend data can be derived and used to avoid spot price anomalies. Although this information was updated as the study progressed, the team did not attempt to forecast raw material prices far out into the future, as it was felt that

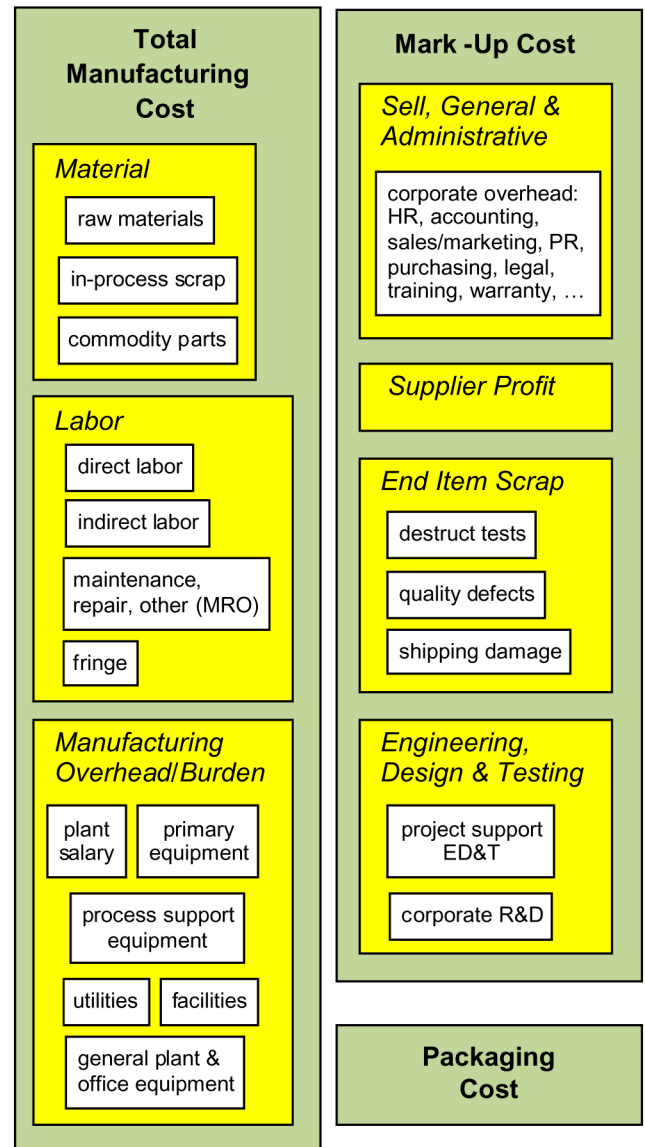


Figure 2. Elements Captured in Direct Manufacturing Costs

this would introduce too much new uncertainty. It was decided instead that raw material price trends should be addressed through sensitivity analysis. Again, the team kept in focus its goal of deriving costs from real hardware and hard data, with opportunity for assessing the impact of trends in input data later.

Ferrous and non-ferrous alloy pricing involved several internet sources, including the U.S. Geological Survey (USGS), MEPS (previously Management Engineering & Production Services), Metal-Prices, London Metal Exchange, stainlesssteel, and Longbow. Resin pricing sources included Plastics News, Plastics Technology Online, Rubber and Plastics News, and IDES (Integrated Design Engineering Systems). Resin formulations are often tailored by manufacturers to serve specific applications and this was

dealt with by grouping resins into ranges. For example, glass filled Nylon 6 components are binned at one of three content levels: 0 to 15 percent glass-filled, 30 to 35 percent glass-filled, and 50 percent glass-filled, each with its own price point. Prices for specialized material formulations or shapes were obtained through discussions with experts familiar with the material selection and pricing used in the products under evaluation or through formal quotes from raw material suppliers. In some cases, a composition analysis was made and prices derived from a known material within the same material family. Obtaining prices for unknown proprietary material compositions, such as powder metals, necessitated consultation with manufacturers and industry market research firms to provide generic pricing formulas, and these were checked against published market prices for similar materials.

Labor

The Labor Database is broken into two industry sections: Motor Vehicle Parts Manufacturing (supplier base) and Motor Vehicle Manufacturing (OEMs). Each has a list of standard production occupations, with mean hourly wages taken from the Bureau of Labor Statistics (BLS) Standard Occupation Classification (SOC) system [11]. These cover the “direct” production occupations involved in the process mapping exercise derived from the teardowns, such as injection mold press operators, die cast press operators, heat treat equipment operators, team/general assemblers, computer numerical control (CNC) machine operators, and stamping press operators. Note that the BLS labor rates include union and non-union labor, reflecting the relative mix of each in the workforce at the time the data was gathered (2009).

There are two other categories of manufacturing personnel supporting the direct laborers that are accounted for in the total labor costs: (1) indirect labor and (2) maintenance, repair and other (MRO) labor. Indirect labor occupations include materials handling, shipping and receiving, quality control, first-line supervision, and manufacturing/process engineering. MRO is the labor required to repair and maintain manufacturing equipment and tools. Examples include electricians, pipe fitters, millwrights, and on-site tool and die tradespeople.

To obtain rates for indirect labor, an average ratio of indirect to direct labor costs is derived for each relevant industry sector (injection molding, for example). The same approach is used for MRO labor. To calculate these ratios, occupations in the BLS data are categorized within each industry sector as direct labor, indirect labor, and MRO labor. (A few occupations falling into none of these categories are excluded from this calculation.) For each of these categories, a total cost per hour is calculated by summing up the population-weighted cost-per-hour rates. Next, the industry sector ratios are calculated by dividing the total indirect or MRO labor costs by total direct labor costs. When multiple industries employ the same type of direct laborer, a weighted average of the top three industries is calculated.

Labor costs also include the fringe expenses the employer must cover in addition to the employee base wage. These include medical and other insurance benefits, pension/retirement benefits, government directed benefits, vacation and holiday benefits, shift premiums, and training. The contribution of fringe to the overall labor rate is assessed as a percentage of direct, indirect and MRO labor. Two fringe rates are used: 52% for supplier manufacturing, and 160% for OEM manufacturing. The supplier manufacturing fringe rate is derived from the BLS database for manufacturing years 2008-2010, by dividing the average supplier total compensation data by the corresponding average wages/salaries data. The OEM fringe rate was calculated using 2006/2007 average North American United Auto Workers (UAW) OEM wage and labor rates of \$28.18 and \$73.21, respectively, and checked against more recent rates as the study progressed.

Manufacturing Overhead

The manufacturing overhead database contains manufacturing overhead rates (sometimes referred to as “burden rates”) associated with various types of automotive manufacturing equipment. The rates in the database are categorized according to primary manufacturing processes and the associated equipment (such as thermoplastic molding, thermoset molding, castings, forgings, stamping and forming, powder metal, machining, and turning).

Manufacturing overhead costs 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
- operating supplies
- perishable and supplier-owned tooling
- plant wages (other than direct, indirect and MRO labor)
- returnable dunnage maintenance (including cleaning and repair)
- intra-company shipping costs.